Dredging Equipment Modifications for Detection and Removal of Ordnance

ESTCP Project MM-0321

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This project was intended to demonstrate separation of military munitions from dredging material on a representative dredge while minimizing the impact on dredging production rates and/or operations and applying appropriate safety precautions. Specifically, to identify an appropriate technology that would provide in-situ separation of entrained military munitions from dredge material in such a way as to reduce the need for dredge slurry post-dredging separation efforts in a feasible and cost efficient manner. During the first year of this effort (Phase I), this project surveyed the domestic and international dredging community to determine if technology was available to accomplish this task.

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EXECUTIVE SUMMARY

OBJECTIVE

This project was intended to demonstrate separation of military munitions from dredging material on a representative dredge while minimizing the impact on dredging production rates and/or operations and applying appropriate safety precautions. Specifically, to identify an appropriate technology that would provide in-situ separation of entrained military munitions from dredge material in such a way as to reduce the need for dredge slurry post-dredging separation efforts in a feasible and cost efficient manner. During the first year of this effort (Phase I), the intent was to survey the domestic and international dredging community to determine if technology was available to accomplish this task and to prepare for a demonstration using a harbor dredge. Project accomplishments during Phase I included (1) a questionnaire combined with response evaluation that attempted to obtain additional information, previously unknown, on dredging projects that involved military munitions in dredge operations; (2) a literature review of known dredging projects in the United States and abroad that have involved dredging in munitions-contaminated sediments with the goal of establishing the scope of the problem, common issues, technical approaches, and status of these projects; (3) a decision flowchart to assist in the planning of a dredging project at a site where military munitions exist and to assist in allowing a project engineer to plan for a dredging project involving munitions; (4) several field trips/conferences to evaluate first-hand, technology(s) that, while not specifically designed for in-situ separation of military munitions, might have potential for that application; (5) project assumptions and boundaries designed to guide the development of a concept for a possible follow-on demonstration plan, and (6) a selection of the most promising technology(s) that might be adapted to provide in-situ separation of military munitions from a dredge slurry.

RESULTS

The first year's effort met all project expectations except for the opportunity to plan a demonstration project using a harbor dredge as a test platform. Four problems prevented the project from meeting this expectation:

1. No identified hydraulic production harbor dredging projects (defined as 40-gpm operation output) existed during the planned testing period involving military munitions-contaminated sediment that would have allowed collaboration between the research team and the operational dredgers.
2. If a production harbor dredging operation had been identified and the demonstration plan had been applied, the dredging contractor potentially would have required monetary compensation due to stand-by time and production loss (around $45K/day), which would have exceeded the planned budget and required additional funding.
3. Demonstration metrics involving a known seeded population of military munitions would have been difficult to achieve on a production harbor dredge project.

4. A production harbor dredging project executed in an uncontrolled environment affected by sea-state and weather would in all probability have resulted in situations such that project objectives would not be completed.

Conclusions and products from Phase I include the following:

1. Confirmation that there is no commercial off-the-shelf technology available that could accomplish the intended objective(s).
2. Selection of screening technology from the sand and gravel mining industry was considered the most promising technology available to meet project objectives.
3. Determination that the most promising solution to the separation issue would be to resolve the dredging problem first using inert shapes, followed by a study on the explosive safety issue.
4. Determination that selection of a dedicated 12-inch hydraulic dredge should be pursued to gather data on the dredging demonstration with confidence in extrapolating to other types of dredging operations.
5. Determination that magnetic and other types of existing in-situ sensors could play only a limited role in the discrimination or identification of entrained military munitions in a dredge pipeline.

RECOMMENDATIONS

Recommendations included the following:

1. This project should be continued into Phase II for a demonstration to provide proof-of-concept of the ability to screen out inert shapes using a 12-inch hydraulic dredge. (This recommendation was not accepted).
2. Explosive analysis should be evaluated and numerically modeled to describe an underwater munitions detonation within an enclosed hydraulic circuit similar to that found in a dredge pipeline. (This recommendation was not accepted).
3. A manual should be developed to review and recommend blast mitigation techniques for use when dredging in munitions-contaminated sediments. This recommendation was accepted and resulted in a request to produce a guidance document on the operation of dredging equipment in munitions contaminated sediments.

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1. INTRODUCTION

1.1 BACKGROUND

The Department of Defense (DoD) is responsible for numerous dredging projects in bays and harbors throughout the United States. Many of these occur in locations associated with past and current military activities. One unforeseen complication when dredging has been the discovery of military munitions within sediments, especially in dredging projects involving the first attempt to remove sediment over extended periods of time (new works). The presence of ordnance in dredged material presents two unique challenges. First, it poses a potential explosive safety hazard to dredging personnel and potential damage to equipment. Second, any subsequent beneficial use of dredged material must also address the possibility of the presence of ordnance presence and/or its removal. Ammunition products produced by or for the DoD are regulated under Subpart M of 40 CFR Part 266, where “munitions” are defined under 40 CFR §260.10. A military munition is classified as hazardous waste if it is a listed waste or exhibits a hazardous characteristic (reactivity). This classification can result in a reduction in dredged material reuse options available to DoD and, in particular, the U.S. Army Corps of Engineers (USACE). Specifically, dredged material containing military munitions is not acceptable for preferred reuse options, including beach replenishment and most upland disposal scenarios unless there is confidence that the ordnance has been removed.

In preparation for the home-porting of *USS JOHN C. STENNIS (CVN74)*, a NIMITZ class aircraft carrier at Naval Air Station, North Island, San Diego, the U.S. Navy was required to dredge the channel to increase the navigational depth. Dredging began in August 1997 with a hopper dredge followed by a cutterhead dredge in early October, with the dredge material being placed on local beaches for renourishment. In mid-September, small-arms shells and an 81-mm mortar round were discovered on a renourished beach, and additional 20-mm rounds and another 81-mm mortar round were also recovered in December. When the second set of ordnance was discovered, all beach replenishment activity was halted. While the ordnance was subsequently removed from the beach, the cost associated with the geotechnical surveys and reprogramming of the dredging effort and the negative public relations activities were significant and unforeseen. Dredge standby costs were up to $75,000 per day while alternatives to the replenishment effort were explored. The “San Diego Channel Report” (Southwest Division Naval Engineering Command, 1998) was initiated in October 1997 to identify and evaluate alternatives for placement of sand near shore and onshore as part of the San Diego Channel Deepening Project. SPAWARSYSCEN – San Diego at the request of Southwest Division Naval Engineering Command submitted a proposal to ESTCP in 2002 to further investigate the potential for in-situ separation and removal of munitions entrained in dredge slurry and provide for demonstration project to provide proof of concept.

Dredging of coastal sediments represents the most significant completed pathway for underwater ordnance items to allow contact with the public. Several technologies currently exist to conduct bathymetry surveys prior to dredging operations. However, while current detection capabilities relating to pre-dredge survey techniques are reasonably successful in identifying large objects at

the sediment surface or just below the sediment surface, these remote sensing technologies become less efficient at detecting small ordnance items and are quite inefficient at detecting ordnance buried deeper within the sediment. In most cases, in-situ detection and subsequent removal of military munitions at the bottom of a body of water is impractical or not required due to (1) technical limitations of current survey detection and screening capabilities, (2) potential disruption of planned or ongoing dredging operations, and (3) perceived lack of exposure of these munitions to human contact (blast safety). Several research and development efforts are currently being funded to extend the capability to detect, locate, and identify military munitions on the surface of the sediment-water interface as well as those buried beneath the sediment surface.

Civilian and military dredging projects have historically encountered military munitions. Intact ordnance and pieces of ordnance have been discovered at dredging sites, in the dredges themselves (dragheads, cutterheads, pumps, etc.), and in the dredged material placement sites (i.e., renourished public beaches). Alternatively, dredged munitions have sometimes detonated and damaged or, in the most extreme cases, have sunk a dredge (U.S. Department of the Army, 1972). There are currently no guidance documents available to assist the owner, manager, engineer, or dredging contractor in planning, designing, and safely operating in a military munitions-contaminated dredging project.

Existing documentation is mostly in the form of internal agency memorandums and reports. Safe separation technology is needed to minimize the dredge crews' and the publics' exposure to military munitions. Guidance documentation is needed not only to provide support in cases where military munitions are likely to be dredged, but also to provide the user(s) with additional information on other aspects of dredging where military munitions are located or may be present (i.e., engineering controls and operating procedures to mitigate detonation damage).

Locating and separating military munitions found in dredging material has been an issue for the dredging community ever since dredging equipment has operated in areas subject to the inadvertent or intentional placement of ordnance in international and, to a lesser extent, domestic United States waterways. Leaving military munitions in the aquatic environment exposes personnel and the public to the danger of potential explosive blast effects associated with human access to explosive rounds. Because of the difficulty in retrieving oversize munitions during a dredging project (those that can be screened off at the dredge suction and therefore not able to pass through the dredge), it was decided that they should be considered separately outside the discussion of this effort. The ability to dredge in military munitions-contaminated sediments and simultaneously separate munitions that are allowed to pass through the dredge would constitute a significant improvement in the existing capability of the dredging community to complete navigational dredging requirements in ordnance contaminated sediments and to subsequently use the dredged material for beneficial purposes such as beach nourishment.

1.2 DEMONSTRATION OBJECTIVE AND SCOPE

The demonstration objective was to provide proof of concept of successful separation of ordnance (down to a 20 mm round) from dredging slurry on a representative dredge, while minimizing the impact on dredging production rates and operations and also applying appropriate safety

precautions. The demonstration proposal consisted of a planned effort at a gravel/sand mining site, using a hydraulic dredge with an operating output of 4,000 gpm and a 30.5 cm (12-in)-diameter discharge pipeline. The issue of separation was initially to be addressed through the use of inert ordnance to evaluate the feasibility of in-situ separation (as opposed to post-processing separation). This was going to be followed by a numerical modeling effort describing the potential blast effects that can be associated with munitions passing into and through a modern dredge and potentially exploding while entrained in the dredge slurry. During the dredging demonstration, inert shapes were to be seeded in two ways: (1) ordnance test units (OTUs) were to be placed in the sediment by SCUBA divers for eventual pickup by the cutterhead, and (2) OTUs were to be directly injected into the discharge pipe to ensure variability in the sample size and to allow 100 percent of the ordnance to pass through the entire dredging process during the demonstration. Separation methods to be tested were to be based on polyurethane physical screens and also on existing magnetic separation technologies.

The proposed demonstration was to be designed for a controlled environment, unaffected by the weather and sea state, which would allow enough time and support to alter variables and allow precise metrics to be collected on seeded OTUs. Information collected from a successful demonstration would have provided stakeholders (e.g., Federal and State Governments, DoD agencies, and private entities) and dredging contractors with screening performance factors to reduce ordnance exposure to crew, and to develop construction and cost engineering estimates, thereby minimizing contractor attendant risk and cost per unit volume dredged. Additionally, it was to allow for a review of the best combination of screening alternatives, which could then be scaled up to a larger navigation dredging project.

As mentioned previously, a demonstration using an operational harbor dredge as originally proposed was a more expensive alternative that would have required monetary compensation to the contractor for production loss of up to $45,000 per day. Also, because live ordnance could be already present at the dredging site, it would be difficult to ensure that proper recovery metrics could be utilized for the experimental design.

The focus of the project was to identify an appropriate technology that would provide in-situ separation of entrained military munitions from dredge material in such a way as to reduce the need for dredge slurry post-dredging separation efforts in a feasible and cost efficient manner. Assumptions that accompany this project are listed in Chapter 4.1. With regard to any continuing efforts to identify and/or demonstrate promising technologies, six boundary conditions were identified for consideration and are listed in Chapter 4.2.

1.3 USE OF TECHNICAL UNITS

Use of metric and English systems of measurement in this document is predicated on the common use for both systems in engineering practice and the exclusive use of English units by the navigation dredging industry. Construction measurement quantities are normally measured in linear feet, square feet, or cubic yards; however, some recent construction plans and specifications use metric units of measure. Because of the variety of mixed measurements, equivalent

conversions have been provided in some instances to promote translation from English units to metric.

1.4 REGULATORY DRIVERS AND OTHER ISSUES

Applicable USACE Regulations (ER 1130-2-520) state that "the maximum practicable benefits will be obtained from materials dredged from authorized Federal navigation projects, after taking into consideration economics, engineering, and environmental requirements in accordance with applicable Federal laws and regulations (33 CFR Parts 335-338), Section 933 of the Water Resources Development Act (WRDA) of 1986, as amended by Section 35 of WRDA of 1988, and Section 207 of WRDA of 1992 provides authority for the Secretary of the Army, if requested by a state, to place beach quality sand dredged in constructing or maintaining navigation improvements on adjacent beaches if the work is deemed to be in the public interest and upon payment by such state of fifty percent of the increased cost." (ER 1130-2-520).

Applicable Navy environmental quality research and development (R&D) requirements for this effort include but are not limited to the following:

- 1.I.02.b Improved Marine Sediment/Dredged Spoil Remediation and Decontamination.
- 1.I.04.e Improved Methods for Removal of Unexploded Ordnance (UXO).
- 1.III.02.f Improved Detection and Location of Unexploded Ordnance (UXO) on Land and Underwater.

Applicable Army environmental quality R&D requirements include but are not limited to the following:

- 1.6.a Unexploded Ordnance (UXO) Screening, Detection, and Discrimination.
- 1.6.b Soil/Sediment Unexploded Ordnance (UXO) Neutralization/Removal/Remediation.

Potential regulatory requirements continue to be the Clean Water Act (CWA) 1977 as amended by National Pollutant Discharge Elimination System Permit Requirements.

During dredging operations, procedures are documented to ensure compliance with environmental assessments, impact statements, permits, and contracts. Environmental impact alternatives are subject to environmental compliance requirements. Where impacts are not considered significant, an environmental assessment (EA) may be considered sufficient environment documentation. When impacts are more significant and affect the public safety, then the applicant would be required to submit an environmental impact statement (EIS). Permitting is required for any changes in dredged material disposal plans and for disposal of oversized dredged materials. Also, if water quality or air quality is affected by the dredging effort, then the existing permits would have to be modified. Contractual compensation may be experienced if there is a change in production rates, or unexpected safety issues involving the contractor, workers, and dredging equipment.

2. DREDGING PROJECTS INVOLVING MILITARY MUNITIONS

Historically, dredging has been required for maintenance and new works projects in channels and harbor basins, and is increasingly being conducted in munitions-contaminated environments. As mentioned previously, there is evidence of several explosions of entrained military munitions occurring in conjunction with dredging operations along with documentation of significant delays, costs, and safety issues related to munitions in dredging material (U.S. Department of Army, 1972; Dredging and Port Construction, 1998). Additionally, it is desirable that military munitions that present an unacceptable risk to a dredge and its crew be excluded from entering the dredge. Also, if military munitions enter and exit a dredge, it is desirable that the munitions be prevented from reaching beneficial use sites (i.e., public beaches). Section 2.1 documents the results of a questionnaire/ survey conducted during the initial phase of this project, while the subsequent sections summarize specific examples of the impacts of military munitions on dredging projects. These additional examples are presented from sources identified from interviews with personnel involved with military munitions-related dredging projects, along with a literature search of dredging magazines, dredging conference proceedings, and Internet inquiries.

2.1 QUESTIONNAIRE/SURVEY RESULTS

A survey questionnaire was developed and distributed to numerous entities participating in dredging operations. The purpose of the query was to identify historical and contact information regarding military munitions that were discovered during dredging operations and the subsequent impacts the munitions had on these dredging operations and the project as a whole. The survey questionnaire (Appendix A) was initiated with an explanation of the reasons and benefits of this particular survey. Initially, the responder was asked to provide contact information, with the option of submitting the survey anonymously. The first two questions of the survey asked if the responder's organization was involved in any dredging projects that have encountered military munitions or if they know of other projects that had involved munitions. Negative replies to both these questions ended the survey. If a positive response was indicated for either of these two questions, additional questions followed for details of the dredging project. The survey questionnaire was distributed to the following entities:

- 62 domestic port commissions
- 37 international port commissions
- 75 domestic dredging companies
- 147 international dredging companies
- USACE district dredging offices

Responses to the survey were limited, with 41 potential dredging respondents replying. Only six of these responses indicated knowledge of military munitions in dredging operations. Five responders had actual knowledge of a project involving munitions. Only two responded with the name of a contact that might provide additional information on a military munitions dredging

project. The impacted dredging sites identified as a result of the survey included (not including those projects that were previously known) the following:

1. Toussaint River Entrance, Ohio
2. Albany Harbor, West Australia
3. Reclamation Hvide Sande, Nymindegab, Danish West Coast
4. Port of Brisbane, Brisbane, Queensland, Australia
5. Kokkola Channel Project, Kokkola, Finland
6. Sandbridge Beach Nourishment, Virginia Beach, Virginia
7. Oresund Link, between Sweden and Denmark

Information reported in the survey is included within the site topics in the following sections. The Reclamation Hvide Sande site listed above is not included because the survey responder was aware of but did not have any direct knowledge of the effort. Further investigation did not lead to additional information on this project site.

Parsons, Brinckerhoff, Quade, and Douglas, Inc. (1999) indicate a common lack of documentation on detection and removal of military munitions and even less on dredging projects involving munitions within the United States. After a literature search in 1999, they concluded that the following factors contribute to the lack of dissemination of military munitions in the literature:

- "When discovered by military operations, the objective is to maintain a low profile and not upset citizens about the presence of UXO. Historically, UXO was taken care of internally by ordnance experts and not publicized. Also, marine UXO has occurred less frequently than upland UXO.
- Discovery of UXO in the U.S. by non-military parties is a relatively new phenomenon. More sites, and the historical uses at those sites, have been exposed since the decommissioning of military facilities in the 1990's.
- As public pressure has mounted to have beaches renourished, there has been a higher exposure to marine UXO. Two of the most recent US projects where UXO was discovered have been beach nourishment-related: Sandy Hook and San Diego Naval facility dredging. The handling of ordnance at Sandy Hook was documented by Corps personnel, but the ordnance aspects of the San Diego project have not been documented and it is reasonable to conclude that the Navy will not be anxious to do so. (The presence of ordnance in this project was very disappointing to communities of southern California and to the design team. In effect, it negated an extensive effort to have material approved for beach nourishment and to add material to beaches in great need of restoration.)
- Contractors are often the first to discover ordnance. Their priority is to deal with it, not talk about it. Few contractors take the time to write technical articles, and "share" how they deal with it as it is against the competitive nature of their business"

2.2 SUMMARY OF HISTORICAL MILITARY MUNITIONS IN DREDGING PROJECTS

A second major effort of this project was to document 15 previous dredging projects known to have encountered military munitions. In some cases, available documentation was limited, such as the Singapore, Vietnam, and Umm Qasr dredging projects, while in other cases documentation available documentation was more extensive, such as Toussaint River, Sea Bright, and San Diego Channel projects.

The historical projects studied varied by the project costs, the extra time experienced because of the presence of military munitions, the safety design controls, requirements for separation methodologies, and whether or not the munitions actually exploded. The increased costs of military munitions during dredging operations varied from an additional $60,000 (Sand Bridge), $9 million (San Diego Channel) to approximately $30 million (Finland). The extra time varied from 2 days (Brisbane), 4 years (Finland), to a beach replenishment project that will continue over 50 years (Sea Bright). The safety design varied by requirements for simply calling in Explosive Ordnance Disposal (EOD) personnel and safety design controls (Eagle River Flats and the Toussaint River) to applying remotely controlled dredging abilities (Finland and the Eagle River Flats). The damage sustained from the military munitions also varied for projects. During the Toussaint, San Diego Channel, and Sea Bright projects, no detonations actually occurred. However, in the Rock Island project, ordnance blew up in the pipe and caused physical damage. In the Malacca Straits incident, a 500-kg bomb became lodged in the suction pump of the dredge. The Ft. Mifflin project actually struck a piece of ordnance in the water and turbulence was observed. The Singapore project had a piece of ordnance explode in a pipe located in a dredge pump room, and during the Vietnam conflict, a dredge was actually sunk, presumably, because of an explosion due to entrained ordnance.

2.3 PORT OF BRISBANE MAINTENANCE DREDGING, AUSTRALIA

During annual maintenance dredging, military munitions were repeatedly encountered. This project annually removes up to 1 million cubic meters of sandy maintenance material via the hopper dredge *Sir Thomas Hiley*. This dredge has a hopper capacity of 2,900 m^3 (3,973 yd^3) and was dredging at the depth of 10 to 20 m (33 to 66 ft). Military munitions were found in the hopper loading system and in the reclamation area. The most likely source of the munitions is related to the fact that the area was formerly used as a dumping ground for waste munitions. The caliber of the military munitions was not identified. On at least one occasion, as a result of the discovery of the munitions, the dredging operation was delayed approximately 2 days as military personnel removed the munitions from the site. (Survey Results, 2003)

2.4 KOKKOLA CHANNEL PROJECT, KOKKOLA, FINLAND

The port of Kokkola is located on Finland's Gulf of Bothnia coast. In 1995, the Finnish Maritime Administration initiated port development projects that included improved access to the channel and land reclamation. During 1997–2001, the depth of the Kokkola channel was increased from 11 m (36 ft) to 13 m (42 ft), with dredging depths to 15.6 m (51.2 ft).

During this operation, the trailer dredge *Nautilus* had to stop work. While dredging in the inner channel, military munitions were found in the trailer's drag head. Subsequent investigation indicated that the port of Kokkola was a previous transit route for vessels carrying decommissioned ordnance from just after WWII to 1974. A depression located 50 km (31 miles) from the port was apparently designated as a final military munitions disposal site during the period in question. Munitions were also disposed of in the adjacent shipping lane. In addition, this area had been bombed during WWII, causing this area to be subsequently assessed as extremely dangerous because of the potential for finding large unexploded aerial bombs.

Dredging operations in the area were delayed while the Finnish Defense Forces and the "Terramare OY" dredging company developed new safety procedures for dredging and for handling the material containing the dredged military munitions. At the same time, it was necessary to determine if unexploded 500-kg aerial bombs existed in the area.

Project planning and modifications were scheduled during the autumn of 1997 into the spring of 1998. Changes to the dredging procedure and dredging equipment were subsequently employed. Based on the inability to determine whether a magnetic signature would represent an explosive or non-explosive object, the plan had to consider blast danger relating to the potential for a large aerial bomb to explode during the dredging process. A remote-controlled dredging approach with a mechanical dredge was developed based on the conclusion that the dredge and personnel working on the dredger could not be protected from the explosion of a 500-kg aerial bomb.

An operating raft was developed to remotely control the dredge functions from a safe offset distance of up to 500 m (1,640 ft). The dredge operator's commands were transferred via radio control from the raft to the dredge. The operator would effectively perform the same actions as if he were on the dredge. Cameras and monitoring equipment were mounted on the dredge to inform the operator (located on the raft) of the dredging parameters and circumstances.

Arrays of magnetometers were towed through the area to locate and identify ferrous magnetic signatures. Remote-controlled dredging was carried out at each ferromagnetic signature location of 37 mm (1.5 in) or greater; otherwise, normal dredging operations predominated. Dredging was remotely controlled within a 10-m (33-ft) radius of the detection points. The total dredging area was approximately 3.5-km (2.2-miles) long and 300-m (984-ft) wide. The volume of material (clay and silt) containing military munitions was estimated at 1.2 million m^3 (1.6 million yd^3). Military munitions found included cartridges, artillery, and grenade launcher rounds, fuzes for artillery projectiles (projectiles ranging from 37 mm to 155 mm in diameter), and aerial bombs of 100 to 500 kg. The ammunition ranged in size from small arms to 0.5 m (1.6 ft) in length and was normally cylindrical.

To dredge in the ammunition-littered region, the dredge *Kahmari*, a remotely controlled grab dredge with a 5 m^3 (6.5 yd^3) clamshell, was used. Additionally, the areas surrounding the ammunition-contaminated region were cleared by using a 7 m^3 (10 yd^3) bucket backhoe, the *Koura*, and a 15 m^3 (19.6 yd^3) bucket grab dredge, the *Meri-Pekka*, both of which were manned. For the manned dredging operations, personnel were protected with bulletproof glass and steel safety partitions.

The material obtained by remote-controlled dredging was transported to a separate disposal area by a split hull barge with a 300-m^3 (392-yd^3) capacity. Material removal/disposal from the barge was remotely controlled from a tug at a standoff distance of 300 m (984 ft). The containment basin for final disposal of the material containing unexploded ordnance was 300 m by 500 m (944 ft by 1,640 ft). A gravel berm surrounding the basin was constructed with 600,000 m^3 (784,800 yd^3) of blasted rock to a depth of 10 m. The basin was backfilled with clean earth material after the dredged material was placed in the basin. The material from the surrounding area was transported by manned 600 m^3 (785 yd^3) split-hopper barges to a reclamation site.

The estimated average production cost of the project was 35-Euros/m^3 ($32.6 U.S. dollars/$yd^3$) for the 1.2 million m^3 (1.6 million yd^3) of material dredged from the channel and placed in the two containment areas. Approximately 42 months were lost because of the discovery of the munitions in this dredging project. The original cost estimate for the channel was 25 million Euros ($30.9 million U.S. dollars). Delays and alterations to the dredge and dredging procedures, as a result of the discovery of military munitions, caused the channel improvement costs to rise to approximately
62 million Euros ($76.6 million U.S. dollars) (TerraMare, March 2004; Survey Results, 2003).

2.5 MEDWAY ESTUARY, UNITED KINGDOM

In 1989, a new-works dredging project, 3 million m^3 (3.9 million yd^3), was conducted in support of a new container port development project with an open-water dredged material placement site in an area not specifically designated for future port development. Previous dredging in this area (predominantly fine to medium sands, with some locations having gravel and “stiff London clay”) had encountered ordnance. In 1971, during a 6- to 7-week maintenance dredging contract, 50 different types of ordnance were recovered. Shells (4 in) and Bofor projectiles (40 mm) were recovered from this same area during a previous 1985 dredging project to remove 2,000 m^3 (2,616 yd^3) of material (Maddrell, 2001).

Restrictions were imposed on the three hopper dredges, *Geopotes XV*, *Volvox Delta*, and *Alpha B* (hopper capacities ranging from 5,000 m^3 and 8,000 m^3 (6,540 yd^3 and 10,464 yd^3) to restrict any ordnance from being deposited in the placement site. Bars (25 mm [1 in]) were installed on the dragheads to form screens with aperture areas of approximately 150 cm^2 (23 in^2). This measure was successful in excluding major ordnance items from the placement site, but significant amounts of ordnance subsequently became jammed in the dragheads. When production fell (due to rocks, clay, debris on the bars), these dragheads had to be raised and cleaned every 20 to 40 minutes. If the cleaning delays exceeded 30 minutes, the contractor claimed downtime (Maddrell, 2001).

From 1989 to 1990, over 770 ordnance items were recovered from this area. Most of these items were inert (cannon balls from the Dutch and Napoleonic wars and inert training rounds), but 32 military munition items required disposal by the Royal Navy. Explosive Ordnance Disposal (EOD) personnel were required to be onboard the hopper dredges to handle the ordnance during the three dredging contracts. “While relatively expensive in terms of specialist staff and down-

time, the cost of this operation was only about 3 percent of the overall project cost of some 6 million pounds ($10.7 million U.S. dollars)" (Maddrell, 2001).

Prior to the first dredging effort, trawlers were used to try to reduce the amount of ordnance being trapped in the dragheads by dragging the bottom for debris. While they did recover some ordnance (approximately 5 percent of what was recovered in the dragheads), the overall evaluation of trawlers was that they were not successful because most ordnance appeared to be buried beneath the sediment surface (Maddrell, 2001).

2.6 ALBANY HARBOR, WEST AUSTRALIA

During a new-work dredging project at Albany Harbor, West Australia, military munitions were discovered. The dredging was being conducted using the *Everglades* cutterhead dredge, *IHC Beave*, outfitted with a 400-mm (16-in) pipeline. Large quantities of small caliber, 20-mm cannon, and 3-inch Bofor ammunition were found. Additionally, a few 5-inch and 6-inch naval shells and a 250-lb aerial bomb were located in the area. Military munitions were also discovered at the pipe head and the cutterhead. The source of the munitions was undetermined.

To guard against the entrainment of military munitions, the dredging process was altered. The cutterhead was fitted with grill bars that allowed the cutter teeth to pass between the 5 cm (2.5 in) openings in the bars and exclude 3-inch and larger shells. In addition, a rock box was fitted behind the cutter wheel to collect the heavy objects and keep military munitions away from the dredge pump and personnel. Blast mats were placed over the pump and piping in restricted areas inside the dredge. Australian army ordnance personnel were present for munition identification and handling. No ordnance pieces were subsequently determined to be fuzed, with the exception of the 250-lb aerial bomb, which appeared to be live. The aerial bomb was taken to a local quarry by army EOD personnel and detonated. The small arms were buried deep under the reclamation area.

The modifications were viewed as a method to work safely, but they slowed the production rate due to the closed off suction mouth and the rock box. The estimate of time lost because of the presence of military munitions was 6 months. Production rates were estimated to be 35 percent of the normal production for similar conditions without military munitions present and averaged 180 m^3/hr (235 yd^3/hr) for the clay material. Dredging depths were approximately 14.5 m (48 ft) in the approximate 125,000-m^2 (13450-ft^2) dredging area. Recommendations for future maintenance dredging suggested the use of a mechanical dredge to facilitate removal of the military munitions left on the seabed (Survey Results, 2003).

2.7 SANDBRIDGE BEACH RENOURISHMENT, VIRGINIA BEACH, VIRGINIA

Between October 2002 and May 2003, approximately 1,520,000 m^3 (1,990,000 yd^3) of sand was removed from two 1-mile square borrow areas and placed by a pipeline dredge on Sandbridge Beach using the hopper dredges, the *Lindholm* and the *R. N. Weeks*. Military munitions were found in the hopper basket and one 5-inch shell passed through to the pump and damaged an impeller without detonating. When the first shells were discovered, the project was shut down for

approximately 3 hours while Navy EOD personnel identified the ordnance. The shells were found to be inert and the dredging was re-initiated. Hundreds of 3-inch-diameter by 15-inch-long shells and 5-inch-diameter by 30-inch-long shells were subsequently found. EOD personnel collected and disposed of the shells. The impact of the military munitions increased the project cost by approximately $60,000, with most of the cost associated with damages to the dredge.

2.8 ORESUND LINK, BETWEEN SWEDEN AND DEMARK

The Oresund Link Project involved dredging a 120-m (393-ft) wide trench between Denmark and Sweden to install a tunnel containing a rail and road link. Various studies were conducted for the multi-year project (site surveys, seismics, and diver surveys), but no ordnance was found in the project area. However, after dredging started, a large World War II bomb was discovered in the dredged material placement area, and two 50-kg bombs were discovered on the dredge barges being filled by the Great Lakes Dredge and Dock's dipper dredge, *Chicago.* Because of the concern that the large cutterhead dredge, *Castor* (dredging the tunnel trench), might be damaged by an explosion by a similar bomb, an ordnance detection survey was conducted in the dredging footprint. This survey consisted of divers with magnetometers, and transects with an eight-channel magnetometer. Fifteen bombs were eventually recovered and disposed of by the Danish Navy, with a survey ordnance-to-target ratio (actual ordnance recovered to ferromagnetic targets detected) of 1 to 72. The survey/recovery effort cleared the area ahead of the dredge without delaying the actual dredging operation. The overall cost of the munitions survey was $5 million, about 1 percent of the dredging contract cost of $450 million, based on 1997 dollar values (Maddrell, 2001).

2.9 TOUSSAINT RIVER NAVIGATIONAL PROJECTS, OHIO

The discovery of military munitions halted dredging in Ohio's Toussaint River in September 1992. A 106-mm mortar shell, which later turned out to be inert, was caught in the dredge's cutterhead. Subsequently, in 1995, the USACE Buffalo District, conducted a demonstration dredging project in the Toussaint River to evaluate the operational effectiveness of a clamshell bucket dredging process that was specifically designed to address the threat related to ordnance in the sediment.

The dredging methodology selected for the demonstration consisted of removing river bottom material with a modified clamshell bucket dredge and depositing it upon separation screens placed over the hoppers of bottom-dump scows. These screens were designed to pass sediment and retain military munitions by a combination of gravity flow and water jet fluidization. As dredged material was dumped onto the screen surface, it was visually monitored by an EOD contractor through a remotely controlled camera system to detect military munitions as the sediment "sifted" through. The layout and the photograph of the dredging system are shown in Figure 2-1 and Figure 2-2, respectively. When a suspicious object was detected, dredging ceased and the item was positively identified. If determined to be an ordnance hazard, it was recovered, transported to shore, and disposed of by the EOD contractor. After filling the bottom-dump scow, the sediment/debris remaining on the screen was cleared by the EOD contractor, and the dredged material was deposited in a near-shore disposal site.

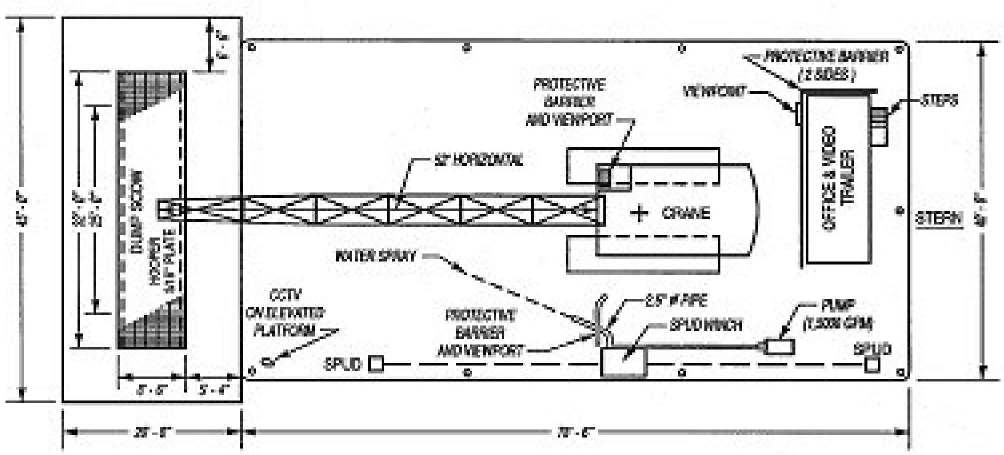

Figure 2-1. Plan view of deck layout.

Figure 2-2. Military Munition Dredging System.

Shoreline Contractors of Lakewood, Ohio, was awarded the dredging contract based on the maximum number of demonstration dredging hours that could be provided within the allocated $500,000 cost constraint. The hourly cost rate included all costs associated with anticipated weather delays, equipment repair, passage of public boaters, transporting and disposal of dredged material, and all other items necessary to meet the specifications. A 24-m (80-ft) boomed crane with a 2.2-m^3 (3-yd^3) toothed-clamshell bucket was used on a spud barge by the contractor for excavating the predominately medium-grained sand (average median sediment grain size of 1.2 mm). An additional 2.2-m^3 (3-yd^3) bucket was held in reserve in case the first bucket was dam-

aged by a detonation. Engineering controls to counter safety hazards because of potential detonation consisted of enclosing the crane operator's booth with a 6-mm (0.25-in)-thick steel plate protection barrier with a viewport consisting of a polycarbonate laminate that provided the equivalent resistance of a 6-mm (0.25-in)-thick mild steel plate, as seen in Figure 2-3.

Figure 2-3. Crane operator's protective barrier.

The 80-ft crane was required because it allowed the operator to maintain a minimum separation distance of 16 m (52 ft) between the operator and the clamshell bucket (also a protective barrier). The U.S. Army Engineering and Support Center, Huntsville, Alabama, designed appropriate safeguards, including the protective barrier and the separation distance, by using the Conventional Weapons Effects Program (CONWEP), a computer program that analyzes effects of a potential detonation (determined by size and type of ordnance found previously). CONWEP was developed as a supplement to the TM5-855-1 "Conventional Weapons Effects" manual and incorporates the equations and empirically based curve fits for trajectory and shell penetration analyses.

A total of 37 pieces of ordnance were recovered from the separation screens and properly disposed. From this total, 31 pieces were classified as inert ordnance and the remaining six as UXO. One of the items is shown in Figure 2-4. An overall production rate of 20.5 m^3/hour (26.8 yd^3/hour) or 205 m^3/day (268 yd^3/day) was attained by the dredge plant at a cost of approximately \$33.26/m^3 (\$25.43/yd^3). EOD personnel support and services incurred an additional cost of \$23.18/m^3 (\$17.72/yd^3). The total demonstration production cost was approximately \$56.44/m^3 (\$43.15/yd^3), as compared to an average cost of less than \$6.54/m^3 (\$5.00/yd^3) for conventional dredging in that part of the Great Lakes (Welp, Clausner, and Pilon, 1998).

Figure 2-4. Recovered 90-mm ordnance on separation screen.

The next Toussaint River dredging project was conducted 27 August 1999 through 11 October 1999, using a modified clamshell dredge and scows, but this time the scows were not equipped with separation screens, a water spray system, or UXO personnel. The general plan indicated channel lines and the upper and lower dredging limits. If ordnance was discovered any time during operations, the contractor was to stop operations in the affected area, mark the location, and notify the contracting officer and the 731st Explosive Ordnance Disposal (EOD) Company, located at Wright–Patterson Air Force Base, Ohio, of the ordnance hazard. An EOD Team was to then respond to the site to evaluate and dispose of the ordnance item discovered.

The contract specifications required that the crane operator be protected by barriers with structural properties equivalent to 2.5-cm (1-in)-thick steel plate protection barrier as compared to the 6-mm (0.25-in)-thick plate required in 1995 (Figure 2-5). Protection was also required for the crew on the spud barge (Figure 2-6), and (unlike the 1995 project) for the scow release operator. Protection for the scow operator was similar to the crane operator's and was located at the scow release-mechanism station (Figure 2-7). A public withdrawal distance, from DoD 60559-STD, Table C8T.2, of 381 m (1,250 ft) between the disposal scow and any other vessel was in effect during disposal operations. No personnel were allowed on the scow during transport operations, and once over the disposal area a single worker was transported to the scow to accomplish the sediment unloading procedure. That worker was required to be behind the protection equipment before opening any of the scow doors.

Figure 2-5. Crane operator’s protective barrier.

Figure 2-6. Crew’s protective barrier.

Figure 2-7. Scow release operator’s protective barrier.

A minimum separation distance of 16 m (52 ft) had to be maintained between the crane operator and clamshell bucket. The crane operator was required to place the dredged material in the scow

as close to the scow's bottom as possible to maximize the amount of protective coverage provided by the scow's steel sides. For public safety considerations, the nearby river channel and surrounding areas were closed to marine interests within the "Public Withdrawal Distance" of 381 m (1,250 ft) of the dredging plant and scows. Marine interests were allowed to use the river channel, within the established "Public Withdrawal Distance" for a maximum of 15 minutes every dredging hour, and during non-dredging periods. If no vessels were waiting to use the channel, the contractor continued the dredging operations.

All plant equipment, including dredging barges, tug, and power boats were required to be capable of navigating safely in water depths (initially) as shallow as 1.2 m (4 ft). Project projections indicated that the minimum-sized scow must be 1,308 m^3 (1,000 yd^3) and that the clamshell bucket must be at least 3.8 m^3 (5 yd^3). One additional clamshell bucket was to be on site as a spare. The contractor used a 3.8-m^3 (5-yd^3) clamshell bucket on the crane and two 1,308-m^3 (1,000-yd^3) scows. Dredged material was transported to an open-lake disposal area in approximately 6 to 9 m (20 to 30 ft) of water. During the entire dredging project, no ordnance was encountered (observed) in the authorized channel. Because separation screens were not used in this project, the presence or absence of ordnance could not be conclusively determined.

2.10 SEA BRIGHT BEACH RENOURISHMENT, NEW JERSEY

The U.S. Army Corps of Engineers New York District and the state of New Jersey undertook the largest beach restoration project ever in the United States, known as the "Atlantic Coast of New Jersey, Sandy Hook to Barnegat Inlet, Sea Bright to Ocean Township." The purpose of this "Sea Bright project" is to protect 19 km (12 miles) of heavily eroded and highly developed northern New Jersey shore from coastal storm damages. The total initial project cost is estimated at $140 million (Federal and non-Federal costs). The primary source for the beach quality sediment is a 7.8-km^2 (3-$mile^2$) area located 1.6 to 5 km (1 to 3 miles) offshore of the southern end of Sandy Hook. Hopper and hydraulic pipeline dredges excavated sediment from the authorized borrow area and transported the sediment onto the beach via near shore pump out facilities or a discharge pipeline. The initial project construction totaled 14.1 million m^3 (18.5 million yd^3) of material. The project is scheduled to be constructed in four phases as individual contracts are awarded per section of beach and designated area within the borrow area (i.e., contracts 1A, 1B, 2, and 3). Fifty years of beach renourishment are programmed into this project.

Construction started in 1994 with the award of contract 1A. Within a short time after initiation of contract 1A with a hopper dredge, several different types and calibers of ordnance were discovered in various places on the hopper dredge and on the newly constructed beaches. The ordnance included 50 caliber, 37 mm, a hand grenade, 254-mm (10-in) projectiles, etc. Cleanup operations were required to locate and remove the ordnance from the beach, and EOD personnel were called several times to remove ordnance from the hopper dredge. The source was determined to be ordnance dredged from the borrow area, although no pre-project data suggested the presence of this contamination. A clam-shell dredge was deployed to the borrow area and subsequently recovered ordnance, which ranged from 3- to 16-in shells. The stakeholders investigated a wide range of alternatives to address the issue of military munitions being present in the borrow area. These alternatives included using alternative borrow sites, using innovative dredging techniques, con-

ducting full-scale borrow military munitions site characterizations for munitions, ceasing the project, and conducting pre-dredge military munitions clearance operations. However, the combination of suction intake screens, and beach quality control measures was determined to be the most feasible option. USACE, after consulting with Huntsville Division, had the contractor install 38-mm (1.5-in) spaced bars on the hopper dragheads to exclude any ordnance larger than 38 mm (1.5 in) in diameter from being entrained. This action reduced hopper dredge production approximately 20 percent for contract 1A.

The various contracts awarded since then have included the same strategy used in contract 1A (single hopper dredge/pump out), several hopper dredges working in conjunction with a hydraulic pipeline dredge, and a hydraulic pipeline dredge working solo. All these dredges were required to install 38-mm (1.5-in) spaced bars on the suction intakes (Figure 2-8; Figure 2-9). Because of the danger of the larger sized ordnance (as found previously), current contract specifications require that the dredging equipment intakes still be equipped with longitudinal bar screens that have a maximum opening of 38 mm (1.5 in) between adjacent bars. The screens are to be constructed out of material that is very durable and wear resistant. During the dredging operation, these screens required inspection daily to ensure their functionality. If rock, rubble, ordnance, or other debris larger than 38 mm (1.5 in) in diameter is found on the beach, contractors are required to remove the object(s) totally at their own cost. If the contractor fails to remove the rock, rubble, ordnance, or other debris, then the completed fill section will not be accepted for payment. During all the pumping operations, the contractor is required to provide personnel to maintain visual control at the end of the discharge line. Radio contact must be maintained such that dredging can be halted in case of an emergency.

Figure 2-8. 1.5-inch aperture screen on draghead.

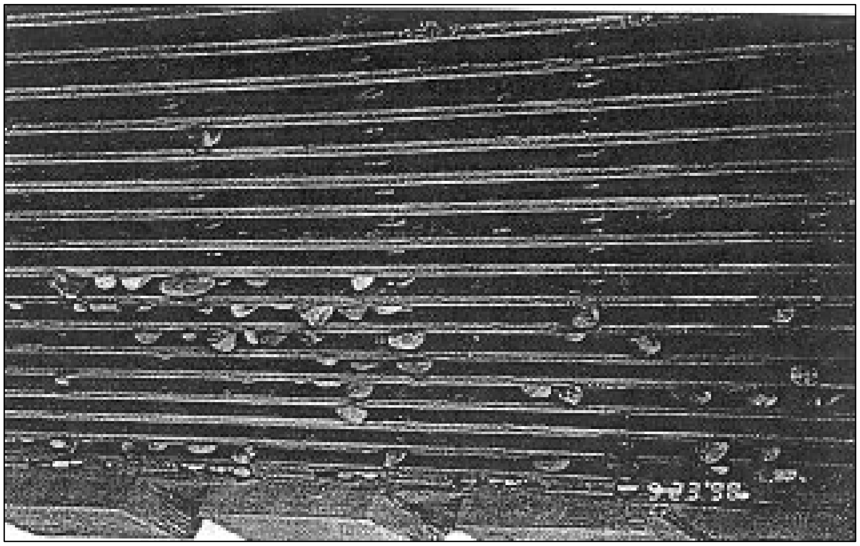

Figure 2-9. 1.5-inch aperture screen on draghead partially blinded by coarse gravel.

Parsons, Brinckerhoff, Quade, and Douglas, Inc., under contract to USACE, conducted the following services to investigate various alternatives to minimize risk to ordnance exposure. They reviewed existing reports and conducted literature searches. Existing conditions and the operations history were summarized. Geomorphic data were researched for the delineation of new borrow sources, and a literature search of the latest underwater ordnance detection and removal technology was conducted. They performed a site visit and conducted interviews with personnel involved with the project. Experts in ordnance detection and disposal were consulted to determine the costs, risks, and feasibility of ordnance detection and cleaning operations in a marine environment. Estimators and project managers from dredging companies were interviewed to obtain cost estimates for augmenting the dredge equipment and estimating the production change associated with using new borrow sites. Permitting agencies were contacted to determine the testing requirements and costs for designating new borrow sites. Cost-effective alternatives for beach re-nourishment were developed. Methodologies and costs were compiled for the alternatives and compared to the current method of screening the dredge dragheads. Based on these results, short- and long-term recommendations were presented.

Four proposed alternatives for supplying sand for beach renourishment projects were suggested. These alternatives are as follows:

1. Characterize the current borrow area (prior to dredging) by locating ordnance for the purpose of avoidance during dredging operations.
2. Remove ordnance from the present borrow site to a level of confidence where ordnance exclusion devices are no longer needed.
3. Improve dredging techniques (to preclude ordnance from passing into the suctionhead) while still preserving worker and public safety.

4. Identify an alternate borrow site free of ordnance that contains required quantities of sand that meet project specifications.

Their evaluation determined that the current draghead and cutterhead screening methods provided an adequate solution to the problem, but because dredging in areas that are contaminated with ordnance poses risk, a preliminary investigation of a new borrow area was recommended. An uncontaminated, more centrally located borrow area “could prove to be the most cost effective long-term solution to beach renourishment on this project and pave the way for the use of federal sand sources for other projects” (Parsons, Brinckerhoff, Quade, and Douglas, Inc., 1999 Draft). For more detailed information concerning this report, refer to Parsons, Brinckerhoff, Quade and Douglas, Inc. (1999 Draft) and Welp, Pilon, and Bocamazo (1998) for overall Sea Bright Project particulars.

2.11 PORT OF UMM QASR, IRAQ

To assist in nation building in Iraq during the summer of 2003, the seaport at Umm Qasr, the main port for delivery of food, equipment, and other humanitarian relief, was dredged by a cutterhead dredge. In the weeks leading up to the beginning of the reconstruction period, Great Lakes Dredge & Dock, assisted by U.S. and British military personnel, removed 200 unexploded objects from the navigation channel. The dredge crew originally tried to exclude ordnance from entering the dredge’s hydraulic circuit by wrapping a wire cable around the cutterhead with an opening of approximately 46 cm (1.5 ft) between wraps and installing a screen with 15-cm (6-in) apertures on the suction mouth, see Figure 2-10. After consulting with the European EOD contractor, the suction mouth screen opening was later reduced to 7.5-cm by 7.5-cm (3-in by 3-in) square openings. However, debris and ordnance would blind this screen by the time the dredge conducted several swings (approximately 15 minutes), so the wire rope wrapped around the cutterhead and the suction mouth screen were removed. The final replacement-screening method consisted of welding bars on the cutterhead itself to construct a screen with 7.5-cm by 7.5-cm (3-in by 3-in) apertures. This modification allowed the dredge to operate several hours before cleaning was required, even when the debris increased as the dredge neared the dock face.

Figure 2-10. Great Lakes Dredge & Dock modifications of cutterhead dredge in Umm Qasr, Iraq.

2.12 BUCKROE BEACH, HAMPTON, VIRGINIA

The information from this project was summarized from Francese, Daniel, and Clark (1997). Shortly after a beach nourishment project commenced at Buckroe Beach in 1990 by the City of Hampton, VA, and USACE, Norfolk District, the operation was shut down because of the presence of ordnance in the transported sand. The sand was being pumped to the beach from an offshore borrow area by a cutterhead dredge. These discovered munitions consisted primarily of World War I and II 70-mm artillery shells (12 in long and 3 in wide). Magnetic surveys were then required to be conducted periodically on material that had been previously placed on the beach as ordnance became exposed to the surface after storms.

The next beach renourishment project in 1996 was designed to safely replenish the beach by instituting engineering controls and operating procedures to protect the contractor workers and the general public. These safety measures included a magnetometer survey that was conducted in the borrow area to minimize contact with the ordnance in the first place, a screen at the suction mouth of the cutterhead to prevent ordnance from entering the hydraulic circuit of the dredge, public notifications (through press releases), and a response plan for dealing with any ordnance that was transported to the beach.

For the magnetic survey, tests were conducted to identify optimum operating conditions and the specific magnetic signature for the 70-mm projectiles. Targets identified during the survey allowed the borrow area to be redesigned to completely avoid the more heavily populated (grouped) locations, and minimize contact with individual targets. A screen with 7-cm (2.75-in) wide apertures (to exclude the 3-in wide projectiles) was also installed on the suction mouth. This screen reduced dredging production by nearly 50 percent as oyster shells, ballast stones, and an occasional ordnance item blinded it after 20 to 30 minutes of dredging, then another 30 min-

utes or so was required to clear the screen. The screen was subsequently removed and bars were welded on the cutterhead (as previously described in Umm Qsar) to construct a “screen” with 7-cm (2.75-in) wide apertures. The redesigned screen reduced production by only 10 percent. One 70-mm projectile came through when one of the screen bars on the cutterhead broke off, and this item was handled by applying the beach response plan.

As a result of the dredging specifications, all bids were 20 percent higher than predicted for the project. Renegotiations with the winning bidder resulted in a smaller volume to be dredged and a reduced project scope for the beach fill as well as increasing the aperture to 7 cm (2.75 inch) from the original specifications of 5 cm (2 in).

A smaller dredge (the *Richmond*) with slower pumping rates used during the 1996 renourishment effort was also considered for use. It was a 12-in, 2000-hp hydraulic cutterhead accompanied by the dredge, *Shenandoah,* as a booster pump. At a slow pumping rate in 1996, it was possible to track the larger items at the discharge. The slurry only arched about 1.5 m (5 ft) from the spreader, and the solids rapidly settled from the fluid. When the original project was executed in 1990 with the use of a larger dredge, the pumping rate exceeded 385 m^3/hr (500 yd^3/hr) and the slurry arched more than 9 m (30 ft) from the outfall pipe. As a result during the 1990 effort, it was difficult to distinguish the large objects from the sand slurry. For more detailed information on this project, refer to Francese, Daniel, and Clark (1997).

2.13 SAN DIEGO CHANNEL, SAN DIEGO, CALIFORNIA

In preparation for the home-porting of *USS JOHN C. STENNIS (CVN74)*, a NIMITZ class aircraft carrier at Naval Air Station, North Island, San Diego, the U.S. Navy was required to dredge the channel to increase the navigational depth. Dredging began in August 1997 with a hopper dredge followed by a cutterhead dredge in early October, with the dredge material being placed on local beaches for renourishment. In mid-September, small-arms shells and a 81-mm mortar round were discovered on a renourished beach, and then additional 20-mm rounds and another 81-mm mortar round were also recovered in December. When the second set of ordnance was discovered, all beach replenishment activity was halted. While the ordnance was subsequently removed from the beach, the cost associated with the geotechnical surveys and reprogramming of the dredging effort and the negative public relations activities were significant and unforeseen. Dredge standby costs were up to $75,000 per day while alternatives to the replenishment effort were explored.

The “San Diego Channel Report” (Southwest Division Naval Engineering Command, 1998) was initiated in October 1997 to identify and evaluate alternatives for placement of sand near shore and onshore as part of the San Diego Channel Deepening Project. This evaluation included investigation of available technologies to remove ordnance from the channel-dredged materials before or during final placement near shore or onshore near the beaches. Concepts proposed during the December public input response period are included, as well as several other alternatives that were considered to provide sand to local beaches using other sources and/or methods. Alternatives were identified and evaluated that considered the following issues:

- Technological viability of screening ordnance and ammunition from dredge material.
- Cost/quantity of sand placed
- Schedule
- Legislation/funding
- Environmental impacts
- Permitting requirements
- Contractual issues

A requirement for the screening of dredged material for beach nourishment was that it had to provide reasonable assurance of removing all ordnance, including small-arms ammunition, 50-caliber, 20-mm, 30- mm, 40-mm, and 50-mm rounds. The requirement to remove all ordnance was particularly problematic. Over half of all the alternatives were eliminated from further investigation because they were not technologically feasible. The remaining alternatives had environmental and safety implications that required varying degrees of environmental impact analysis that could have affected the project schedule. Extensive delays for environmental documentation and permitting would have necessitated contract termination to avoid excessive standby costs. Alternatives for screening involved technologies that were untested and unproven for the quantities, flow rates, and material characteristics of the project. In short, no technologies or processes for sand screening were found to be practical within the schedule and funding constraints of this project (Southwest Division Naval Engineering Command,, 1998). The U.S. Navy decided to dispose the dredge spoils offshore and incur the extra costs to dredge sand from a separate borrow area and place it on the beaches to meet the terms of agreement with the California Coastal Commission.

A valuable resource, clean sand uncontaminated with ordnance, was lost. An additional cost of \$9 M, approximately 20 percent of the project cost, was incurred to replace the material that was subsequently disposed of in a deep-ocean location (Southwest Division Naval Engineering Command, 1998).

2.14 MALACCA STRAITS, MALAYSIA

An article titled "WWII Bomb Causes Malaysian Military To Close Off Busy Sea Lane" (UXOInfo.com, 2004) notes that "A 500-kg WWII Bomb was discovered when it became jammed in the suction pump of a sand-dredging vessel operating about 7 km off the northwest coast of Penang Island in the Malacca Straits, one of the world's busiest shipping lanes. Explosive disposal experts identified the UXO as a Japanese bomb that was most likely dropped from the air during WWII. Japan occupied what is now Malaysia during the war. Two mine sweeping ships were deployed by the Malaysian military to perform mine-sweeping operations near where the bomb was found to search for additional UXO. The busy shipping lane was closed to traffic for several days while the search took place (UXOInfo.com, 2004)."

2.15 MISSISSIPPI RIVER, ROCK ISLAND DISTRICT

The cutterhead dredge, *Rock Island,* a 50-cm (20-in) discharge diameter dredge, was working on the upper Mississippi when it encountered a piece of ordnance in 1939. An article in *Safe Channel* (U.S. Army Corps of Engineers, 1939) describes this encounter. Figure 2-11 shows a ripped-open section of discharge pipe.

Figure 2-11. Ripped-open discharge pipe.

Figure 2-12 shows another picture of the ripped open section of discharge pipe mentioned in the article. The cause of the explosion was not immediately known as is evident by the question in the article: "Are mines being sowed in our 'Old Mississippi'?". The records are not clear at this point, but it is thought that Rock Island continued working the project until another piece of ordnance was found at the disposal site and operations were subsequently suspended. A barge-mounted dragline was then used to complete the project. It is not known whether this dragline was initially on site to assist the cutterhead dredge in rocky areas, or if it was specifically selected for the task of dredging the area with potential munitions. The dragline was side-dumped to a barge where the deposited load was visually inspected for munitions. Using this method, the artillery shell shown in Figure 2-13 was recovered (Welp, Clausner, Pilon, Pope, and Lewis, 1994).

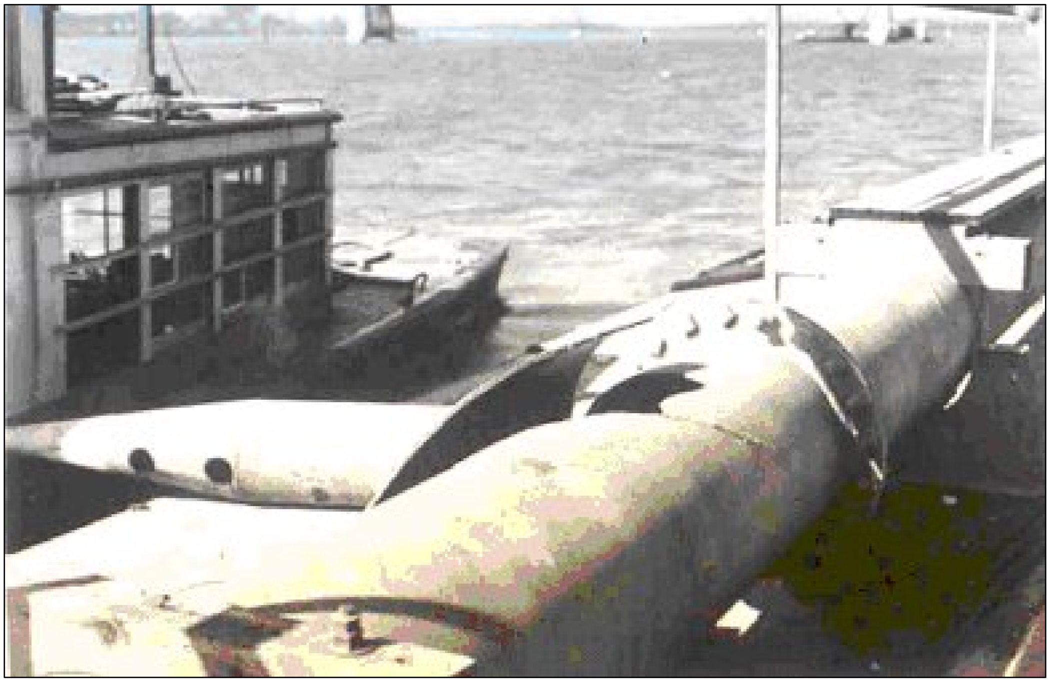

Figure 2-12. Discharge pipeline damaged by military munition explosion.

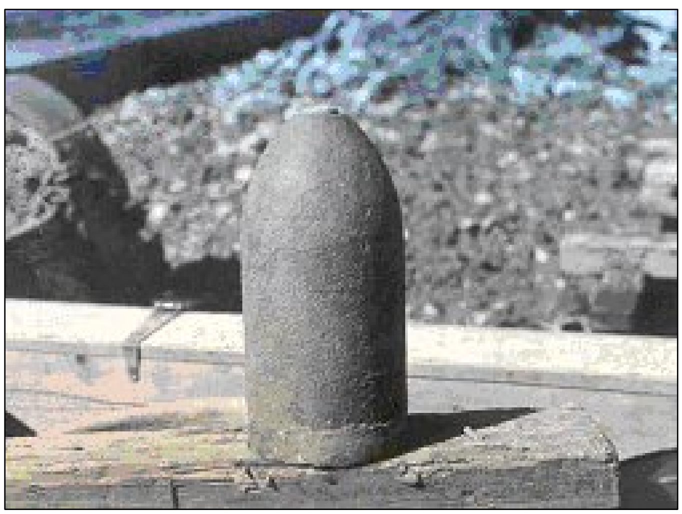

Figure 2-13. Ordnance recovered from dragline and barge operation.

2.16 EAGLE RIVER FLATS, ALASKA

Investigations indicated that an annual waterfowl die-off at the Eagle River Flats (ERF) site was caused by ingestion of white phosphorus (WP) particles introduced into shallow pond sediments by WP munitions training. The USACE Cold Regions Research and Engineering Laboratory (CRREL) was actively involved in these investigations and later conducted a demonstration to

investigate the feasibility of remediating the WP-contaminated sediment. The demonstration involved using a hydraulic pipeline dredge to excavate the contaminated sediment and to transport it to a combined disposal facility (CDF). The treatment process at the CDF consisted of atmospheric drying/natural attenuation.

Constraints affecting dredge feasibility, selection, and design studies and adverse impacts to included wetlands had to be minimized. The water depth at the ponds, with surface areas of 2 hectares or less, varied between 2.5 cm and 50 cm (1 and 20 in), with depth fluctuations occurring only with extreme high tides and river stages. WP and military munitions contamination were present in the sediment. This contamination required the dredging system to provide worker safety precautions and equipment survivability or replacement to counter the potential detonation of military munitions, e.g., 100-kg (500-lb) bombs, WP munitions, or 155-mm high-explosive projectiles (Walsh, 1996).

This effort used a remote-controlled 15-cm (6-in) discharge hydraulic dredge (Figure 2-14) equipped with a shrouded, center-feeding auger head. It was designed primarily for lagoon pumping with a submerged pump/boom auger suction. The dredge was equipped with a 15-cm (6-in) centrifugal dredge pump and 2.4-m (8-ft) auger, both driven by a hydraulic piston pump coupled to a 50-hp electric motor. Biodegradable and non-toxic hydraulic oil was used in the hydraulic system to mitigate spills that might be caused from a detonation. The small size and weight of 5,443 kg (12,000 lb) of the dredge facilitated overland transportation to the remote site. The shrouded auger head was selected to minimize sediment/WP resuspension. Lateral and longitudinal movement was provided by an electric motor-driven winching assembly that traversed a cable anchored at both endpoints. The endpoint anchors consisted of concrete blocks set by helicopter to minimize intrusive operations (i.e., setting spuds) into the substrate contaminated with military munitions.

The dredge was modular in design to facilitate repairs in case of detonation, and pump and control systems were located as far away from the auger head as possible to minimize potential detonation damage. In case of a catastrophic detonation, spare parts (including an extra auger head) and a complete second dredge were held in reserve on-site. The ability to operate the dredge remotely allowed a separation distance to be maintained between the operating dredge and personnel (Walsh, 1996).

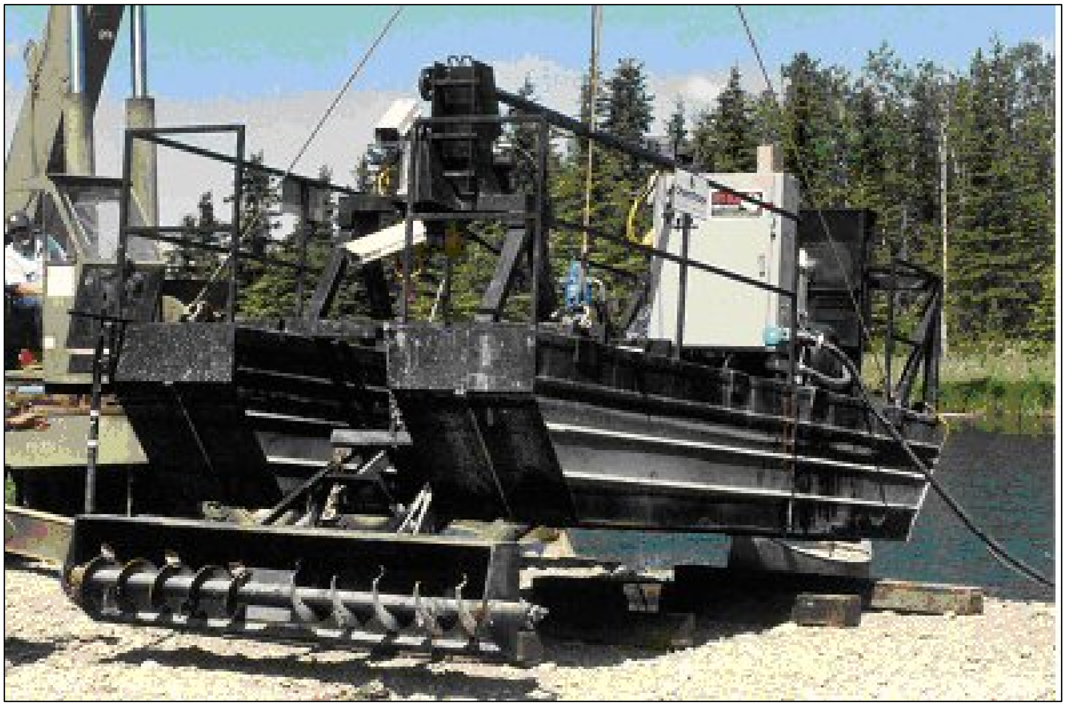

Figure 2-14. Electric remote-control lagoon pumper.

The dredge's operation was controlled from a shore station enclosed in a protective enclosure (Figure 2-15), and a minimum separation distance of 40 m (130 ft) was required to be maintained between it and the dredge. This cab was constructed of 127-mm (0.5-in)-thick welded steel with a 317-mm (1.25-in)-thick ballistic polycarbonate view port. This structure was blast-tested in two separate trials by detonating a 105-mm, high-explosive round supported on wooden crates approximately 60 cm (2 ft) from the ground surface and oriented with the base of the round facing the cab at a distance of about 37 m (120 ft). Only minor damage caused by shell fragmentation was incurred by the cab during the test detonation (Walsh, Chamberlain, and Garfield, 1994).

Figure 2-15. Dredge operator's control station.

Various methods of excluding military munitions at the suction mouth were tried during the demonstration that included screening the inlet (Figure 2-16), separating ordnance in a flow expander box (also known as a rock box), and adding a grate to the expander box. The expander box (Figure 2-17) was designed to allow the denser military munitions to drop out of suspension by reducing slurry flow velocity by increasing suction pipe cross sectional area. Even though these alternatives were effective in excluding ordnance from the pump, they eventually failed because vegetation and woody debris clogged the suction or lodged in the pump. Additionally, neutrally buoyant wood and lighter aluminum pieces would not always drop out into the expander box. When a coarse screen was installed inside the expander box, the screen "quickly plugged, crippling the dredge in a matter of minutes" (Walsh and Collins, 1998). The exclusion device ultimately selected for the project was a modified suction mouth screen/cutter device (see Figure 2-18 with the cutter welded to the auger shaft) that extended the time that the dredge was able to operate. For more detailed information about this project, refer to Walsh and Collins (1998).

Figure 2-16. Screen over augerhead suction mouth.

Figure 2-17. Eagle River Flats Project expander box.

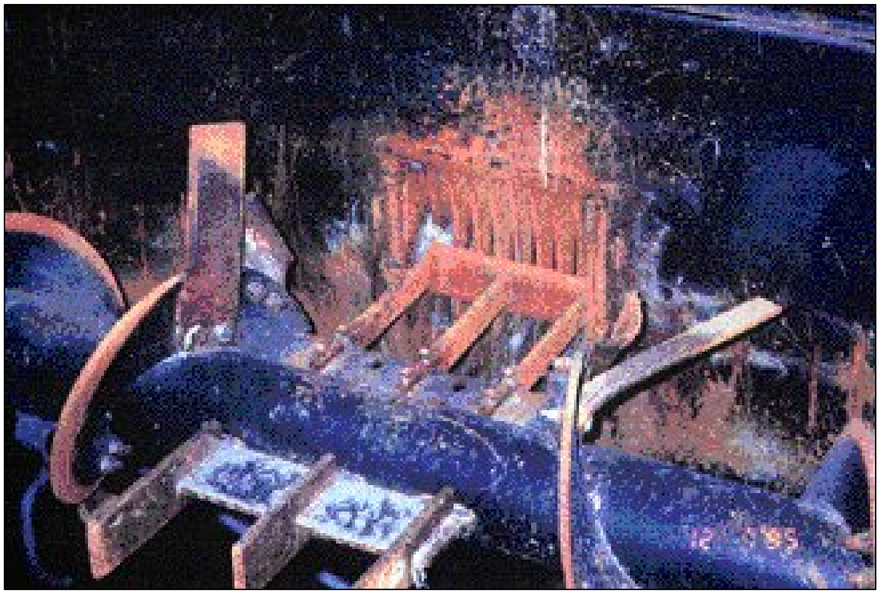

Figure 2-18. Suction mouth screen/cutter device.

2.17 (FORT MIFFLIN) PHILADELPHIA NAVAL YARD, PHILADELPHIA DISTRICT

During the early 1990s, the U.S. Navy had a number of reserve fleet ships moored at the Philadelphia Naval Yard. During routine maintenance dredging, small-arms ammunition and ordnance reported as 40-mm anti-aircraft rounds were observed in a dredged material placement site containing material transferred from earlier projects. While the southern portion of the basin was being dredged by a cutterhead dredge in 1993, the dredge apparently struck an underwater object, with the following observations:

> "The hydraulic dredge crew noticed turbulence in the water about 15 m (50 ft) off the bow of the dredge. A two-foot radius of fire ignited on the surface of the water and burned for approximately 1 minute. Dark colored smoke was produced from the fire. Other smaller pockets of fire ignited on the surface of the water in areas of turbulence. One of the crew members said the air had the smell of burning rubber. The entire incident lasted approximately 2 to 3 minutes." (Memorandum to File, U.S. Navy ROICC Philadelphia)

Because of this event, the dredging method was changed. A bucket dredge was used and dredged material was placed into bottom dump barges and hauled to another site for dumping and subsequent rehandling. A grizzly screen with approximately 15 cm by 15 cm (6 in by 6 in) openings was placed on the barges and material dredged from close to the dock face was screened through the grizzly. No other ordnance was observed, and the dredging job of the south part of the basin was concluded without incident (Ogden Beeman & Associates, 1994).

The Ogden Beeman & Associates report (1994) states the following:

> "Navy wants to proceed with dredging of the remainder of the basin. The area to be dredged is occupied by a number of ships, some of which are reported to date back to the end of WWII. The Corps of Engineers has expressed concern about the previous experience and the Navy wants to address this problem prior to issuing plans and specifications for the work. There are two issues to be addressed:
>
> - What are the implications of dredging ammunition and putting it through the dredging equipment?
> - What are the means available to prevent or mitigate the disposal of ammunition at the Ft. Mifflin disposal site?"

This report further discusses alternative solutions and associated costs for blocking larger ordnance from entering a pipeline dredge by:

1. Installing bars or rods between the blades of a standard "basket" type cutter
2. Welding a "rock ring" on the inside of the back ring of the dredge cutter
3. Installing an expanding section in the suction pipeline to cause heavier material to drop out of slurry suspension (similar to the Eagle River Flats expander box).

Additional commentary mentioned methods for screening material prior or during the disposal to include the following:

1. Grizzly screens for mechanically dredged material
2. Screens at the discharge of a cutterhead pipeline dredge

2.18 SINGAPORE

A hopper dredge was operating in Singapore when "Overall production was slowed after the first day when what was believed to be a piece of small ordnance exploded inside a pipe in the pump room. When Dredging and Port Construction personnel visited the vessel the next day, the silt-splattered ceiling of the massive pump room was evidence of the previous day's disruption. Subsequently, dredging on one side required 70 minutes to fill the hopper as opposed to the usual 40 minutes, but otherwise work continued as normal" (Dredging and Port Construction, 1998).

2.19 VIETNAM

"Safety measures were imperative for dredging in areas where the marine bottom was peppered with live explosives…. On 22 September 1969, the U.S. Navy owned 69 cm (27 in) pipeline cutterhead *Sandpumper* sucked up live ordnance from the bottom of the My Tho River and sank following a detonation of the explosives. For a period of four months, attempts were made to raise her, but, as in the case of the *Thu Bon I*, a cost survey revealed that salvage and repair were not economically feasible" (U.S. Department of the Army, 1972).

2.20 QUALITY ASSURANCE REPORT FOR P-326 SEDIMENT SCREENING, SAN DIEGO, CA

The Naval Station (NAVSTA) San Diego has had a history of mothballing inactive ships, repairing naval vessels, and providing logistical support to locally based units. Since the 1900s, ordnance-handling activities such as loading and unloading have been practiced on and near the piers. In 1999, a dredging project discovered ordnance near the piers and the effort was discontinued. As it became more evident that ordnance was being encountered in portions of San Diego Bay, two issues were considered: worker safety during dredging operations and limited disposal options for ordnance containing dredged sediments. The P-326 Report was initiated to conduct field tests using various processes and technologies regarding post-processing of sediment to separate ordnance. It assessed the potential efficacy of these technologies by computing cost, processing rates, physical properties of sediments, implementation ability, and effectiveness in finding ordnance in dredged sediments. Screening tests were conducted at the mole pier on NAVSTA San Diego property, on approximately 2 acres surrounded with a continuous berm. A “single batch” size of dried dredged sediment was selected to be 20 yd^3 for this project into which inert 20-mm rounds were placed. Various types of separation techniques were used to quantify the effectiveness of detection and removal. The types of techniques included visual, geophysical, and mechanical. Visual screening included inspection of the oversize materials discharged from the mechanical process. The geophysical technologies included a gradiometer and a pulse-induction metal detector. The mechanical processes included various types of rotating, vibrating, and inclined screens, specifically square mesh, harpwire, and trommel screens. The mechanical screens were variously combined with visual and geophysical screening methods.

The final result showed that a visual inspection as a stand-alone process was the least costly, whereas the 2.54-cm (1-in) rotating (trammel) combination (visual) process was the most costly. The visual inspection took the least time, and the rotating trommel took the longest time. The visual process only captured 10 percent of the ordnance test units (OTUs), while the trommel captured 76 percent. The 2.54-cm (1-in) mechanical, vibrating screen yielded a 100-percent capture rate, which was the only test completed in the project that retrieved all OTUs.

3. TECHNOLOGY REVIEW AND ASSESSMENTS

3.1 DREDGING TECHNOLOGY REVIEW

3.1.1 Decision Flowchart to Assist in the Planning of a Dredging Project at a Site Where Military Munitions Exist

A decision flowchart was developed to assist in the development of a plan for addressing dredging in ordnance-contaminated sediments. This diagram begins with an evaluation of the likelihood that military munitions will be encountered during the dredging operation, through the use of a historical review. Results of this evaluation define whether conventional dredging is viable or whether special dredging procedures must be used. If known, the characteristics of the military munitions (type/ caliber/age) would also be determined and documented during this phase. The flowchart is shown in Appendix B.

Detection, classification, identification, and disposal of military munitions are currently performed by the diver-based, point-search, and clearance method. This process typically involves a minimum of a four-person team capable of searching an acre per day under favorable uncluttered conditions at depths under 50 feet. Divers may be assisted by hand-held lights, magnetometers, or sonar, but visual recognition in clear water or tactile inspection of targets in turbid or dark water is still essential. Disposal is by time-consuming underwater detonation, or by individually raising items considered safe to move to the surface for detonation on land. Towed sensors are available that can identify larger military munitions protruding from the surface of the sediment-water interface (so-called “proud” ordnance) under ideal conditions, but currently no system is available that can accurately survey and map the location of military munitions and reliably discriminate munitions from debris.

Once it is determined that military munitions issues need to be addressed during the dredging operation, four general paths evolve in the decision flowchart. These paths are based on whether the objective is to remove munitions from (1) the dredge site, (2) the placement site, (3) neither site, or (4) both. All paths address the safety of the personnel and dredge/placement equipment. In cases
2 and 3, where munitions are not required to be removed from the dredge site, then the dredging operation is simplified by excluding the military munitions from the dredge and leaving it on the seabed (for hydraulic dredges only). For case 4, the dredge site and the dredge material placement site require that the munitions require removal, separation, and disposal. Specifically, when the dredge site and the placement site require that the munitions are to be removed before dredging or transportation through the dredge followed by the separation of the military munitions, then the focus of the munitions handling needs to be on the safety of the personnel and equipment. This case 4 path includes four subpaths that address the following:

1. Selecting new sites, if possible, to avoid military munitions issues
2. Clearing military munitions from the dredge site before dredging

3. Excluding military munitions during dredging and using post-dredging cleanup of the munitions on the seabed
4. Separating military munitions from the dredge material and collecting them during the dredging and placement process

Subpath 4 of case 4, the separation of the military munitions from the dredge material and collection of the munitions during the dredging and placement operation, is the primary focus of this project. A "rejection threshold" is identified as the diameter of military munitions that will be excluded from the dredging operation at the suction end of a hydraulic dredge. Any military munitions larger than this size would be left on the seafloor. Multiple criteria are suggested to select dredge types and separation methods. Additionally, a variety of separation methods are identified in the decision flowchart for application at various locations in the dredging process for the different dredge types.

As the final phase of the decision flowchart, all alternative paths are evaluated on multiple criteria. The alternatives are reviewed and the optimum alternative is selected. The decision flowchart also recommends that dredging and placement plans need to be well documented.

3.1.2 Equipment Used for Army/Navy Dredging

This section includes a description of the major dredging equipment used in dredging activities in the United States (USACE Dredging, in prep). These descriptions provide background information to explain different screening technologies as they apply to various dredge types. Dredging can be defined as the process of excavating sediments and other materials, usually from underwater locations, including the transportation and placement of dredge material to construct new waterways, maintain existing waterway dimensions, obtain fill for land reclamation, improve beach nourishment, contribute to dike and levee construction, create wetlands and marshes, obtain materials from borrow areas, or other beneficial uses.

The process of dredging consists of the following stages (Spigolon, 1993):

- Excavation (loosening or dislodging) of the material from the bottom
- Removal of the loosened material to the dredge vessel
- Transportation of the material (in the dredge vessel, via pipeline or in a separate barge) to the placement area
- Placement of the material

The mechanisms used in the various stages of a dredging operation are a function of the type of equipment used and the characteristics of the sediment dredged. Each of the four dredging stages is accomplished using one or a combination of hydraulic and mechanical devices. Depending on the project, these stages may be modified by additional actions, i.e., blasting rock before excavation. Final placement may include manipulation of the sediment, i.e., shaping or even drying and compacting the sediment.

Dredges used in USACE and U.S. Navy projects are usually classified by either the hydraulic or mechanical manner in which they achieve the excavation and removal stages. Hydraulic and mechanical dredges have enabled the transformation of rivers and harbors throughout the world into navigable waterways, allowing the transport of commerce and people where water passage was historically unavailable. The hydraulic dredge has been a major contributor to this transformation by providing for the movement of large quantities of dredged material in a relatively short time.

3.1.2.1 Hydraulic Dredges

Hydraulic dredges are characterized by their use of a centrifugal pump to dredge sediment and transport it, in a liquid slurry form, to a discharge area. The major types of hydraulic dredges are hopper dredges and cutterhead pipeline dredges. These dredges are named for the method they use to transport dredged material from the dredging site to the placement area.

Hydraulic pipeline (cutterhead) dredges are normally non-self-propelled dredges that use a mechanical cutter to break up the material, which is then excavated hydraulically and transported to the placement site through a pipeline. The hydraulic pipeline cutterhead dredge (Figure 3-1) is the most commonly used dredge type and is generally the most efficient and versatile. It performs the major portion (63 percent) of the dredging workload in the USACE dredging program. Because it is equipped with a rotating cutter apparatus surrounding the intake end of the suction pipe, it can efficiently dig and pump all types of alluvial materials and compacted deposits. This dredge can pump dredged material long distances to upland disposal areas. "Slurries of 10 to 20 percent solids (by dry weight) are typical, depending upon the material being dredged, dredging depth, horsepower of dredge pumps, and the pumping distance to disposal area. If no other data are available, a pipeline discharge concentration of 13 percent solids by dry weight (145 parts per thousand) should be used for design purposes. Pipeline discharge velocity, under routine working conditions, ranges from 4.5-6 m/sec (15-20 ft/sec)" (USACE, 1987)

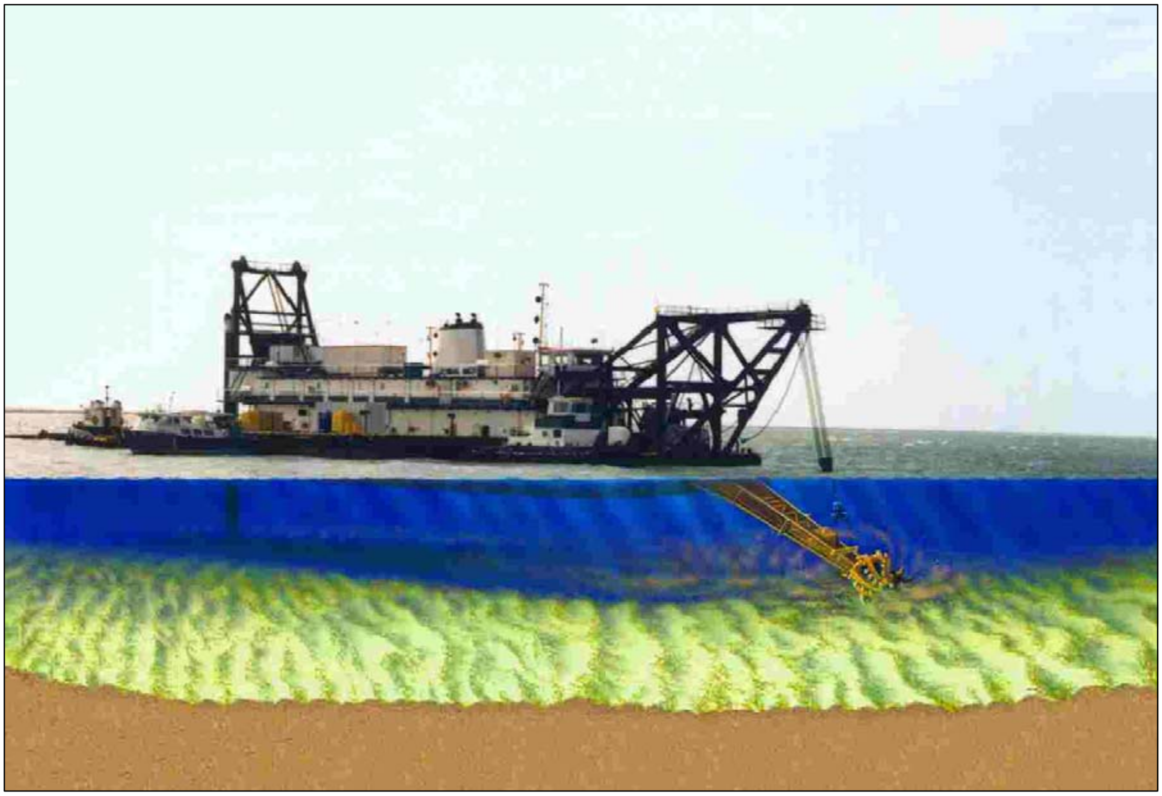

Figure 3-1. Hydraulic cutterhead pipeline dredge.

Another type of hydraulic dredge is the trailing suction hopper dredge. Hopper dredges are sea-going vessels that excavate material hydraulically and transport it inside the dredge into a hopper is built into the vessel's hull (Figure 3-2). Hopper dredges are equipped with propulsion machinery, sediment containers (hoppers), dredge pumps, and other special equipment required to perform their essential function of removing material from a channel bottom or ocean bed and placing that material in open water or upland sites. Hopper dredges have propulsion power adequate for required free-running speed and dredging against strong currents and excellent maneuverability for safe and effective work in rough, open seas. The hopper dredge hull is compartmented with one or more hoppers. Normal configuration has two drag arms, one on each side of the ship. A drag arm is a pipe suspended over the side of the vessel with a suction opening called a draghead. The drag arm is connected to a dredge pump, usually located inside the hull. In some cases, the dredge pump is located on the drag arm to increase its hydraulic efficiency. The draghead is moved along the channel bottom as the vessel moves forward. The dredged material is entrained into the draghead, up the drag pipe, and deposited and stored in the hoppers of the vessel. After the hopper is full, the dredge stops pumping and sails to the placement site where the dredged material is either gravity-dumped out of the hoppers or pumped ashore (after being refluidized and pumped from the hopper).

Figure 3-2. Hopper dredge.

3.1.2.2 Mechanical Dredges

Mechanical dredges are characterized by the use of some form of bucket to excavate and raise the bottom material. A mechanical dredge is shown in Figure 3-3. They are not normally used to transport the dredged material to the ultimate placement area. In some cases, the dredged material can be deposited directly in-water or on the bank immediately adjacent to the dredging area. Normally, the mechanical dredge deposits material into a barge that transports the material to the placement site.

Figure 3-3. Mechanical (clamshell) dredge.

The percentage of total average annual yardage (198 million yd^3) dredged by Corps Districts with contracted (non-government dredge plants) and government dredges is broken down by the respective types of dredges shown in Figure 3-4. In this figure, the pipeline dredge category includes a limited number of pipeline dredges, hopper dredges, bucket dredges, and the “other” category, which includes projects that involved more than one type (hydraulic or mechanical) of dredge.

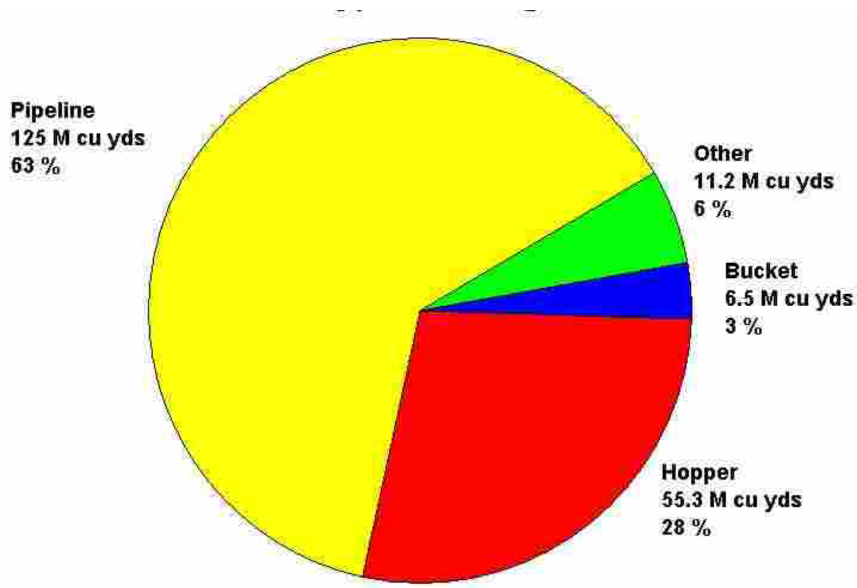

Figure 3-4. Percentage of work conducted by dredge type of an average annual yardage (FY 1996–2001) of 198 million yd^3/year (includes USACE and contractor plant).

Factors that influence the selection of dredging equipment and method(s) used to perform the dredging include the following:

- Physical characteristics of material to be dredged
- Quantities and physical layout of material to be dredged
- Dredging depth
- Location of the dredging and placement sites and distance between them
- Physical environment of and differences between the dredging and placement areas
- Contamination level of sediments
- Method of placement
- Production required
- Type of dredges available

As shown in Figure 3-4, mechanical dredges dredge only 3 percent of the total USACE navigation dredging program. Cutterhead dredges are the most widely used dredges in the world. USACE dredging operations are accomplished most of the time with a hydraulic dredge; of these, about 63 percent of these projects use a cutterhead dredge (this percentage also includes the limited yardage dredged by dustpan dredges). Discharges from cutterhead and hopper dredges are similar. Table 3-1 presents the total slurry volume discharge rate (both water and solids) as a function of inside discharge pipe diameter and slurry velocity inside the pipe.

Table 3-1. Hydraulic pipeline dredge discharge rates (yd^3/sec) (m^3/sec) and (gallons per minute) (Discharge rate = pipeline cross sectional area x slurry velocity).

Slurry Velocity in Pipeline	**Discharge Pipe Diameter**			
m/sec (ft/sec)	**12 in (305 mm)**	**18 in (457 mm)**	**24 in (610 mm)**	**34 in (865 mm)**
3 (10)	0.29 (0.22) (3,523)	0.65 (0.5) (7,877)	1.16 (0.9) (14,100)	2.33 (1.78) (28,285)
4.5 (15)	0.44 (0.33) (5,285)	0.98 (0.75) (11,876)	1.75 (1.33) (21,207)	3.50 (2.68) (42,429)
6 (20)	0.58 (0.44) (7,047)	1.31 (1.0) (15,875)	2.33 (1.78) (28,236)	4.67 (3.57) (56,572)
7.6 (25)	0.73 (0.56) (8,808)	1.64 (1.25) (19,874)	(2.91 (2.23) (35,265)	5.84 (4.46) (70,715)

3.1.3 Pneuma Pump

The Pneuma system was the first dredging system to use compressed air instead of centrifugal motion to pump slurry through a pipeline (Pneuma s.r.l., no date). Mechanical operating parts do not come in contact with the sediment. The system consists of two support pontoon barges and a trailing pump. The mechanical equipment and operating personnel are located on the barges and the pump trails a safe distance behind the barge. If a detonation occurs, it is likely that only the pump would be affected. The system can also be supported from a crane. The pump body itself consists of three cylinders outfitted with shovel blades located at the intake (Figure 3-5 and Figure 3-6). During towing of the system, the shovel blades cut through the in-situ sediment and exclude large objects such as ordnance. Once the pump body is lowered to the sediment, an alternating process of filling the chambers with sediment or water and then forcing compressed air into the chamber to evacuate the sediment out through exhaust pipes dredges sediment from shallow waters as well as great depths. The process is shown in Figure 3-7. In Stage 1, hydrostatic water pressure (or a vacuum system in shallow water) creates suction in the cylinder and causes the chamber to fill with sediment. In Stage 2, when the chambers are filled, the inlet valve on the bottom of the cylinder automatically closes. In Stage 3, compressed air is then supplied through the valve (or exhaust pipe) at the top of the cylinder. The air performs as a positive displacement piston to force the material up and out through the discharge pipe. When the cylinder is nearly empty of sediment, the distributor discharges the air, releasing the internal pressure and the cycle begins again (Pneuma s.r.l., no date).

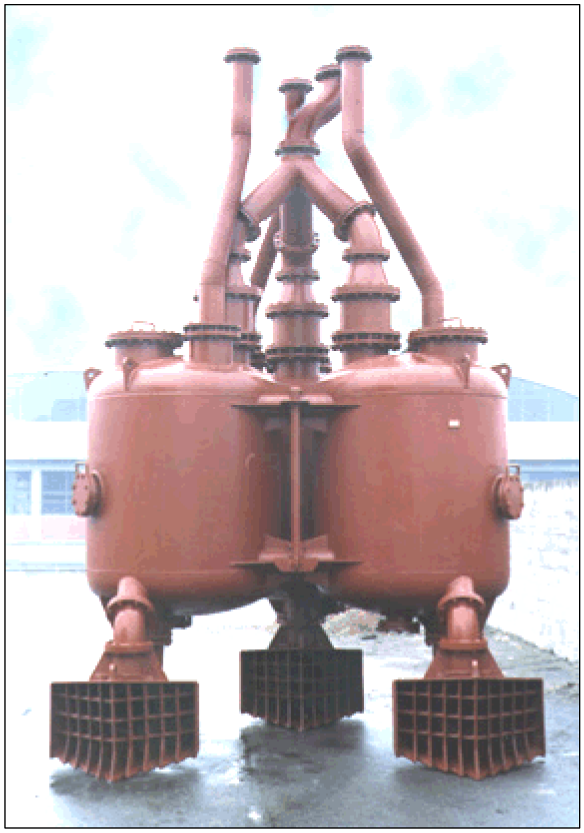

Figure 3-5. Pneuma pump body with Shovel Blades.

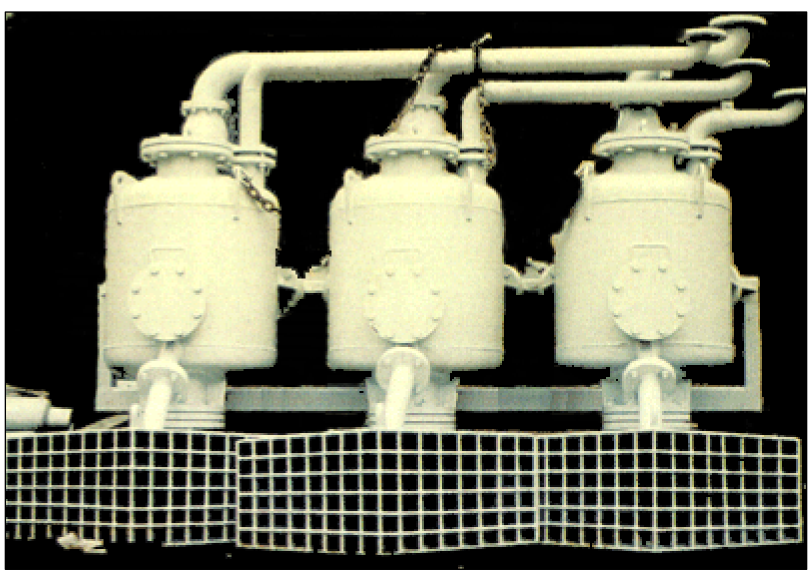

Figure 3-6. Another type of Pneuma pump body with Inlet Pipes.

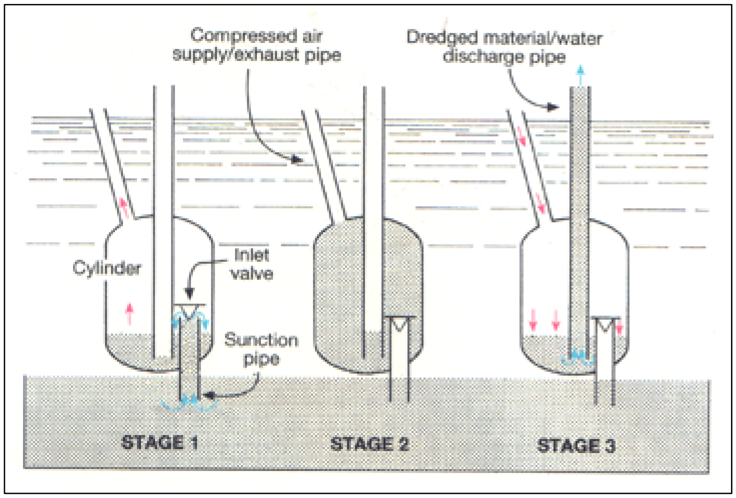

Figure 3-7. Stages 1 through 3 of the Pneuma Pump System pumping principles.

The Pneuma trailing system is generally used for compacted cohesive bottom materials (clay and compacted silts) and is available in a variety of model sizes. The vendor lists output ranges from 40 m^3/hr to 1,800 m^3/hr (52 yd^3/hr to 2354 yd^3/hr) and offers solid concentrations of up to 90 percent solid. Field tests on a Pneuma model 600/100 conducted by USACE found that material could be dredged at almost in-situ density in loosely compacted silty-clay, typical of many estuarine sediments.

Information supplied by Pneuma identified a dredging site in which the system had been used in an area containing munitions, but the details of the sites were limited. In 1995, the Italian Governmental Oil Group, LA Spezia Bay, Italy, at the entrance of the harbor of Portovenere, was constructing a gas pipeline terminal jetty. SNAM Company began dredging with a cutterhead suction dredge at a depth of approximately 10 m (33 ft). A bomb exploded inside the dredge and destroyed the pump room. The crew was not injured because they were not in the pump room at the time of the explosion. IMMER Company then used a Pneuma pump with an output rate of 200 m^3/hr (261 yd^3/hr) and completed the project without incident because of the shape of the shovels and the low trawling speeds. The origin of the military munitions was thought to be dumping of munitions by the Italian Fleet, present in the harbor at the end of WWII (Tempus, Aug. 2003).

3.2 SCREENING SEPARATION REVIEW

3.2.1 Location of Screens

Theoretically, screens can be placed either before or after the pump on a hydraulic dredge to screen out “large” and “small” items. Large aperture screens (or grates) are commonly deployed on the suction head to keep oversized material from entering the pipe. Oversized material is a

function of the maximum-sized spherical object capable of being passed through the pump's impellor.

3.2.1.1 Screening at Suction End of Dredge

For the hydraulic pump to operate efficiently, a suction head opening of 150 percent of the hydraulic pipe area is required (Southwest Division Naval Facilities Engineering Command, 1998). Therefore, depending on the size of the suction screen opening and the quantity of material greater than the screen size, "small-aperture" screens used on a hydraulic dredge at the suction end, near the intake, would not be a viable option. The production rate will be dramatically decreased because of reduced flow by material clogging the screen, and reduced suction head area by the screen itself (increased head losses). This can lead to a decrease in flow (and lowered production rates) through the hydraulic pump. In the worst case, the suction could clog rapidly and subsequently cause a water hammer to develop, or if clogged progressively, cavitation might be the result, with both scenarios possibly damaging the pumping system (Southwest Division Naval Facilities Engineering Command, 1998).

Southwest Division Naval Facilities Engineering Command (1998) presented a general relationship between the screen (grate) size and production at the suction head (Figure 3-8) for the San Diego deepening project site conditions. It indicates that production loss can start at a grid size of approximately 11 inches for dredging material. The first dredging contract at Sea Bright had the contractor install 38-mm (1.5-in) spaced bars on the hopper dragheads to exclude any ordnance larger than 38 mm (1.5 in) in diameter from being entrained. This action caused a reduction in hopper dredge production of approximately 20 percent for that project's site-specific conditions.

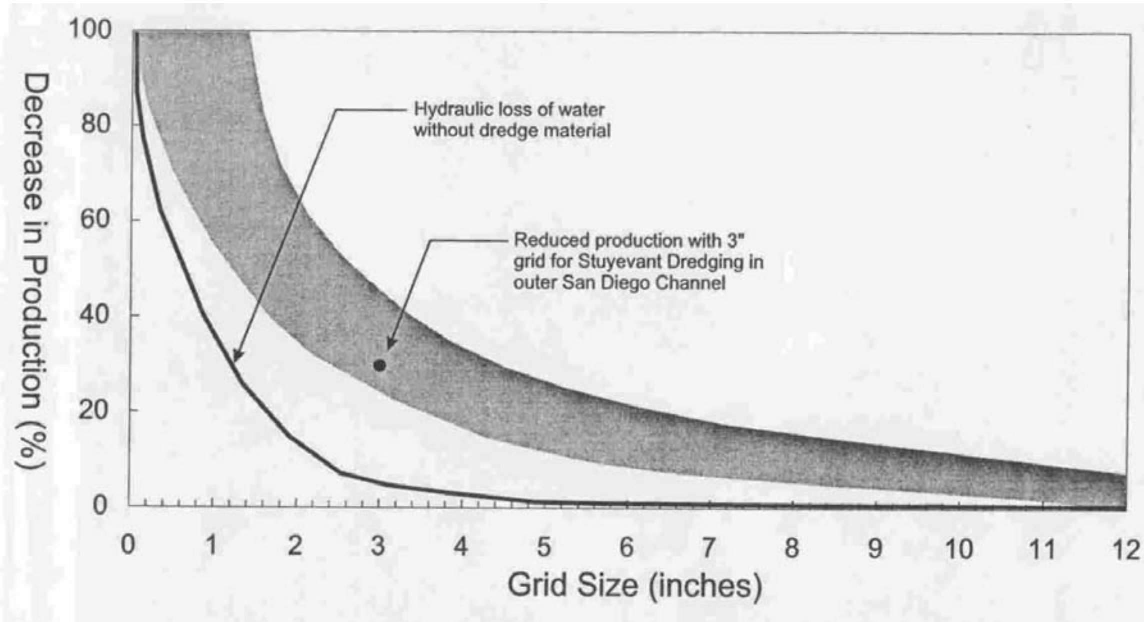

Figure 3-8. General relationship between production and screen (grid) size at suction head.

Impacts on cutterhead dredge production rates from screens placed at the suction end are illustrated by data from the Buckroe Beach and Umm Qasr projects.

At Buckroe Beach, screens were installed at the suction mouth (the suction pipeline opening inside the cutterhead basket) with 7-cm (2.75-in) wide apertures to exclude 3-inch wide projectiles. This screen reduced dredging production by nearly 50 percent as oyster shells, ballast stones, and an occasional ordnance item blinded it after 20 to 30 minutes of dredging, then another 30 minutes or so was required to clear the screen. This **rectangular** screen was subsequently removed and **parallel** bars were subsequently welded this time on the cutterhead basket to construct a “screen” with 7-cm (2.75-in)-wide apertures. The redesigned screen only reduced production by 10 percent compared to the previous 50 percent.

At Umm Qasr, the dredge crew originally tried to exclude ordnance from entering the dredge’s hydraulic circuit by wrapping a wire cable around the cutterhead basket with an opening of approximately 0.5 m (1.5 ft) between wraps and installing a screen with 6-inch apertures on the suction mouth, again inside the cutterhead basket. Because of the munitions exposure risk, the screen on the **inside of the suction mouth opening** was later reduced down to 7.6 cm by 7.6 cm (3 in by 3 in) square openings. Similar to Buckroe Beach, this screen became quickly clogged (blinded) with debris and ordnance, so the wire rope wrapped around the cutterhead and the internal suction mouth screens were removed. The final replacement-screening method consisted of welding parallel bars on the **outside of the cutterhead** itself to construct a screen with 7.6-cm by 7.6-cm (3-in by 3-in) apertures. This modification allowed the dredge to operate several hours before cleaning was required

3.2.1.2 Screening at the Discharge

For practical application purposes, “small-aperture” screens should be applied to the discharge end (after the pump) to minimize hydraulic impacts. Possible screen placement locations include on the dredge itself, on a barge-mounted processing plant, or on the beach. Factors affecting the viability of these screening locations for a given dredge and hydraulic pumping system includes the following (Southwest Division Naval Facilities Engineering Command, 1998):

- Size of screen
- Quantity of material larger than screen size (oversized) and handling and disposal of that material
- Physical constraints of the dredge
- Location of placement site for oversized material

Additional factors that impact viability include project site-specific conditions, i.e., wave and current conditions and physical constraints of a barge-mounted processing plant.

Factors affecting the viability of screening alternatives on or near the beach include the following (Southwest Division Naval Facilities Engineering Command, 1998):

- Size of screen
- Quantity of oversized material
- Available staging area to process and stockpile sediment
- Location of oversized material stockpile and disposal site

3.2.2 Physical Screens

Hydraulic dredges have been used for years to recover sand and gravel from water bodies for construction uses. Equipment is commercially available, as standard items and custom-designed installations, to separate the sand and gravel from the dredged material (Mallory and Nawrocki 1974). Separation technologies vary from mechanical separation technologies such as grizzly screens, trommel (or rotating) screens, and vibrating screens, which separate material based solely on physical size, to separation technologies such as spiral classifiers that are based on both physical and density properties. Some of these separation technologies are considered technologically viable for removing military munitions from dredged material to make the sediment suitable for beneficial uses (Southwest Division Naval Facilities Engineering Command, 1997).

Mallory and Nawrocki (1974) defined and evaluated system concepts for separating, handling, and drying of dredged material that are applicable at confined disposal facilities (CDF) to extend containment area life expectancy. Because military munitions can be viewed as another form of oversized material that requires separation, certain aspects of this study can be applied to the removal of military munitions from dredged material. Selecting the best screening system for a particular project is “somewhat of an art,” with the two most important selection criteria being

screen size opening and flow-rate characteristics. Other selection criteria include equipment and operational costs, plant hydraulics, debris handling requirements, and availability.

Physical separation techniques on the discharge end of a dredge can be used to remove oversized material, debris, and military munitions to produce an acceptable dredged material. Physical screens vary from the simple mechanical removal, such as grizzly screens, shredders, trommel, or vibrating screens, to a combined approach for separation, such as spiral classifiers that are based on physical and density properties (ERDC, 2001).

Table 3-2 describes the separation range that each physical screen is able to achieve. Mechanical removal includes using a clamshell dredge or a backhoe (conventional earthmoving equipment) to separate large debris from the bulk of the dredge material (Engineering Research and Development Center, 2001).

Table 3-2. Separation range for physical screens.

Operational Specifications for Physical Separation Equipment	
Mechanical removal	>60 cm
Grizzly screens	>2 cm
Trommel screens	0.006 to 0.055 cm
Vibrating screens	0.001 to 2.500 cm

3.2.2.1 Grizzly Screens

The grizzly screen rejects oversized material such as boulders, large stones, pieces of concrete, railroad ties, tires, tree limbs, etc. Grizzly screens are usually used in the beginning of a separation process. They are the simplest and coarsest devices for removing debris and are made up of inclined parallel bars spaced from 2 cm to 30 cm (0.8 in to 12 in) apart. These bars can be either stationary or vibrating. For land-based operations, the dredged material is loaded onto the screens by conveyor, bucket, or front-end loader. Grizzly screens require little maintenance (Engineering Research and Development Center, 2001). Main features of grizzlies include coarse sizing, low cost, heavy load bearing capacity, high capability, and wet ore tolerance (Cummins and Givens, 1973). Grizzlies can be arranged in parallel or series to accommodate very high flows to achieve classification of coarse materials (Cullinane et al., 1990). The overall dimensions of a grizzly screen depends on parameters including size of the feed, percentage of undersize material present, slope of the screen, and spacing between bars. The loading capacity of all grizzlies increases as the space between the bars increases (Mallory and Nawrocki, 1974).

In wet sand and gravel operations, the slurry usually enters a classification system through a grizzly screen called a “scalping” pump box as shown in Figure 3-9, courtesy of Eagle Iron Works. These units use inclined fixed bars usually spaced 2.5 cm to 10 cm (1 in to 4 in) to remove oversized debris and rock. Debris flows off the screen face by gravity and is collected in hoppers. The box also reduces the slurry velocity for subsequent processing operations (Mallory and Nawrocki, 1974).

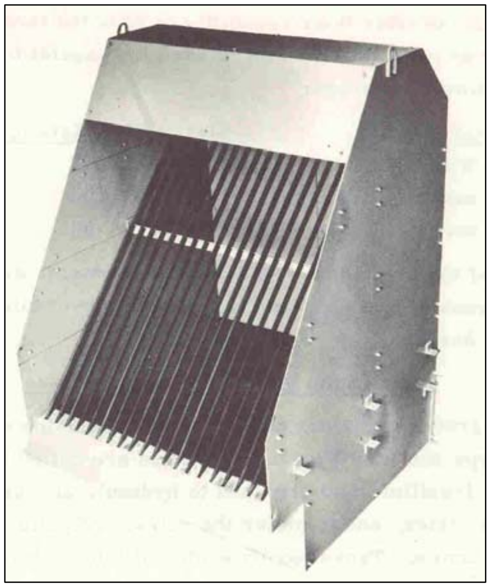

Figure 3-9. Scalping type pump box.

Gravity (static/angled) screens use a stationary inclined screen deck to separate oversized material from the slurry and are similar to grizzlies in operation, but usually have smaller screen opening sizes (Cullinane et al., 1990). Because static screens contain no moving parts, maintenance requirements are also minimal. Various materials are used to construct the screen, including wire cloth, long-slot wire cloth, perforated plate, profile wire, polyurethane, rubber, and soft or self-cleaning rubber. Proper screen selection depends on parameters that include material abrasiveness, material impact, material size, moisture content, cost-effectiveness, and noise level.

In wet applications, rubber will work, but polyurethane screens area also available. Polyurethane has a slick, non-porous, abrasive-resistant surface that generally increases the wear life of the screen. Though initially more expensive than steel screens, the polyurethane screening surfaces are economical because of corrosion resistance (corrosion and rust on the screens are eliminated) and improved ability to reduce blinding (material filling in and clogging the screen). The polyurethane's molding process allows the module's cross members to be manufactured with tapers, so if the sediment or debris is small enough to enter the minimum aperture (opening) on "top" of the screen, then throughput of the material is facilitated by the ever-increasing aperture size as it falls through the screen. Polyurethane's slick nature will also cause oversized material to have a greater tendency to slide down the inclination and off the screen.

Figure 3-10 shows a gravity (static) screen process plant used to separate gravel from a slurry transported by a 254-mm (10-in) cutterhead dredge working for the Standard Gravel Company in Franklinton, LA. The process plant is 1.2-m wide by 2.4-m tall (4-ft wide by 8-ft tall) with an inclined polyurethane screen section that is 2.4-m wide by 0.9-m tall (11-ft wide by 3-ft tall) with 4.8-mm (3/16-in) openings. Maximum screen throughput is approximately 5,000 gpm with an

average range slurry-specific gravity of 1.15 to 1.2 and a maximum of 1.4. As slurry feed enters the process plant, it enters a diffuser box to reduce its velocity head (energy) and channel the flow to promote more efficient screening. The undersized material that flows through the screen (sand and water) is transported by pipes (Figure 3-10) while the dewatered, oversized material (gravel) travels down the inclined screen (Figure 3-11) to a collection area.

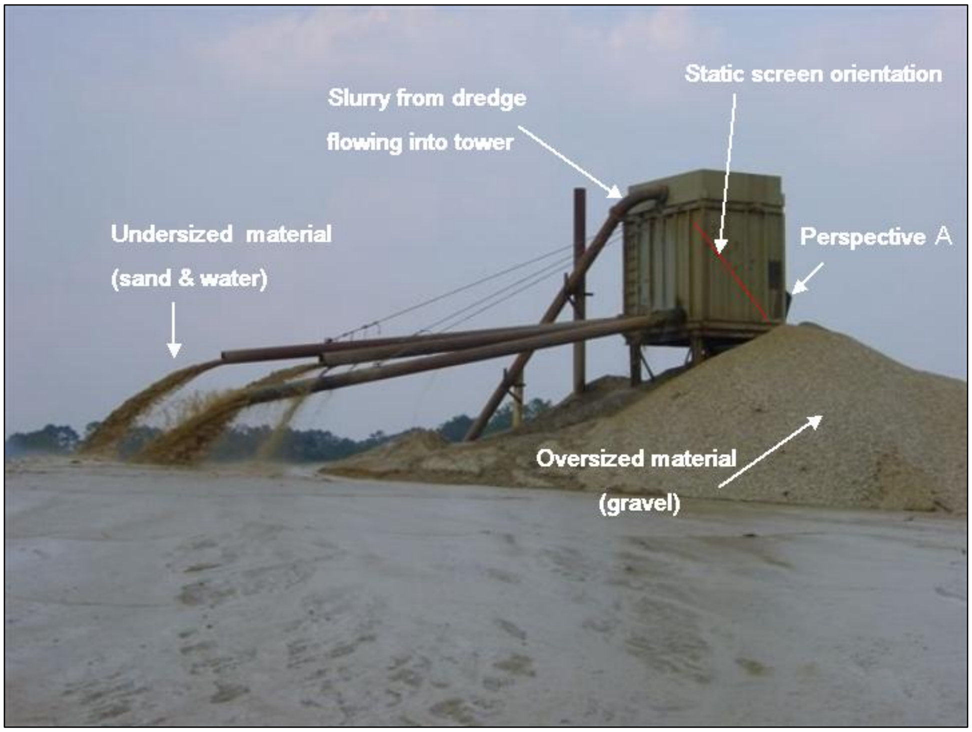

Figure 3-10. Gravity (static) screen process plant.

Figure 3-11. View from Perspective A in above figure of dewatered, oversized gravel traveling across (down) static screen.

During the San Diego Channel project, screening alternatives were investigated to remove ordnance from sand placed in the near-shore zone and directly onshore by cutterhead and hopper dredges (Southwest Division Naval Facilities Engineering Command, 1997). The cutterhead dredge used in the project was Great Lakes Dredge and Dock's dredge, *Florida*, pumping through an 864-mm (34-in)-diameter discharge pipeline. The hopper dredge was the *Stuyvesant*, which pumped ashore approximately 6,000 m^3 (7,800 yd^3) of sand per hopper load through a 900-mm (35.4-in) - diameter "pump out" discharge pipeline. To remove the smallest ordnance item (50-caliber round), a screen opening of 7.9 mm (5/16 in) was required. Static screens were also evaluated for possible application to the hopper dredge, on barges, and on the beach.

The screening option (under the existing contract) on the hopper dredge itself was deemed technically infeasible because of the quantity of material to be screened and the physical constraints onboard *Stuyvesant.* The same alternative under a new contract onboard a different hopper that may not have had *Stuyvesant's* physical constraints was determined to be technologically viable (but not implemented).

The screening alternatives which were considered for the San Diego project consisted of two configurations for operations using barges placed next to the dredge: placing a transferable screen over each barge at the filling location(Figure 3-12) or pumping the slurry to a processing barge, commonly call a spider barge because of its spider-like appearance, that would screen the

slurry and in turn load other barges along side the processing barge (Figure 3-13). Under a new contract, both of these alternatives were considered technologically viable (but not implemented).

Figure 3-14 and Figure 3-15 show plan and profile views of this conceptual static screen application respectively for beach operations. Sediment characteristics in San Diego consisted of sand with an estimated 5 to 7 percent of oversized material (greater than 7.9 mm (5/16 in)) which was unsuitable for beach renourishment consisting of cobbles, gravel, biological shells, ordnance, etc. The estimated screen surface (deck) area to process a slurry flow of 100,000 gpm (at a pipe velocity of 11 m/s (36 ft/s)) with a solids content (by volume) of approximately 19 percent (or 1.1 m^3/s of solids) was in the order of 100 m^2 (1,075 ft^2) (Southwest Division Naval Facilities Engineering Command, 1997).

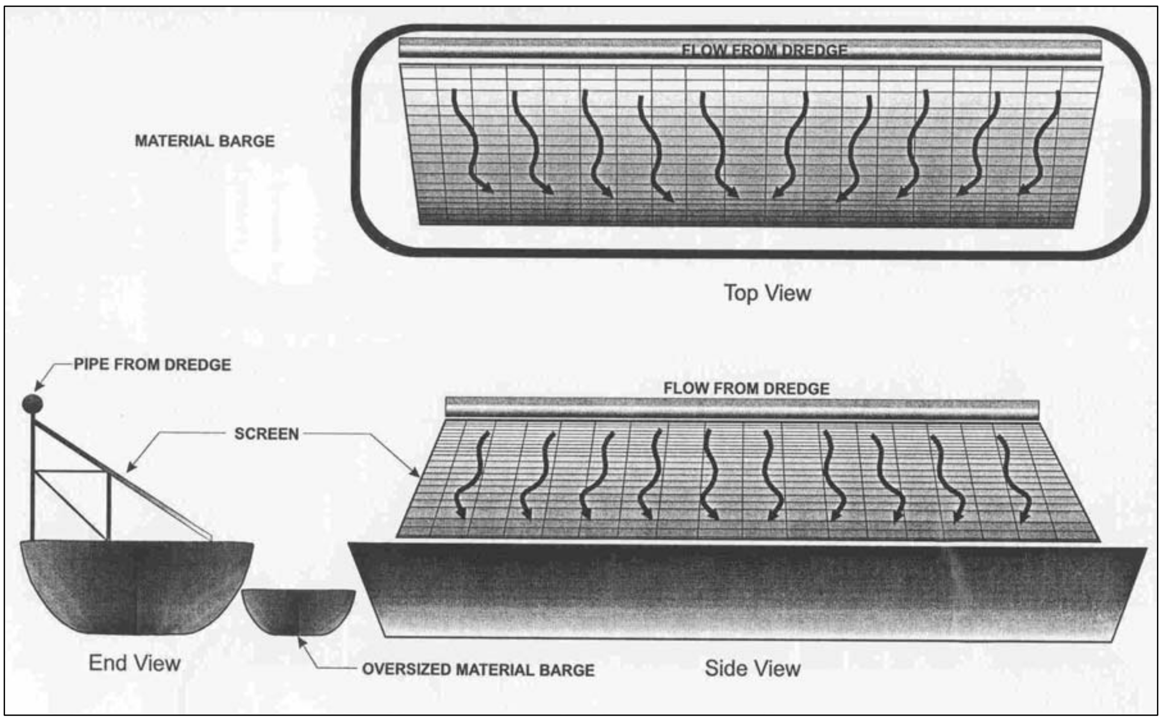

Figure 3-12. Transferable static screen placed over barge during loading.

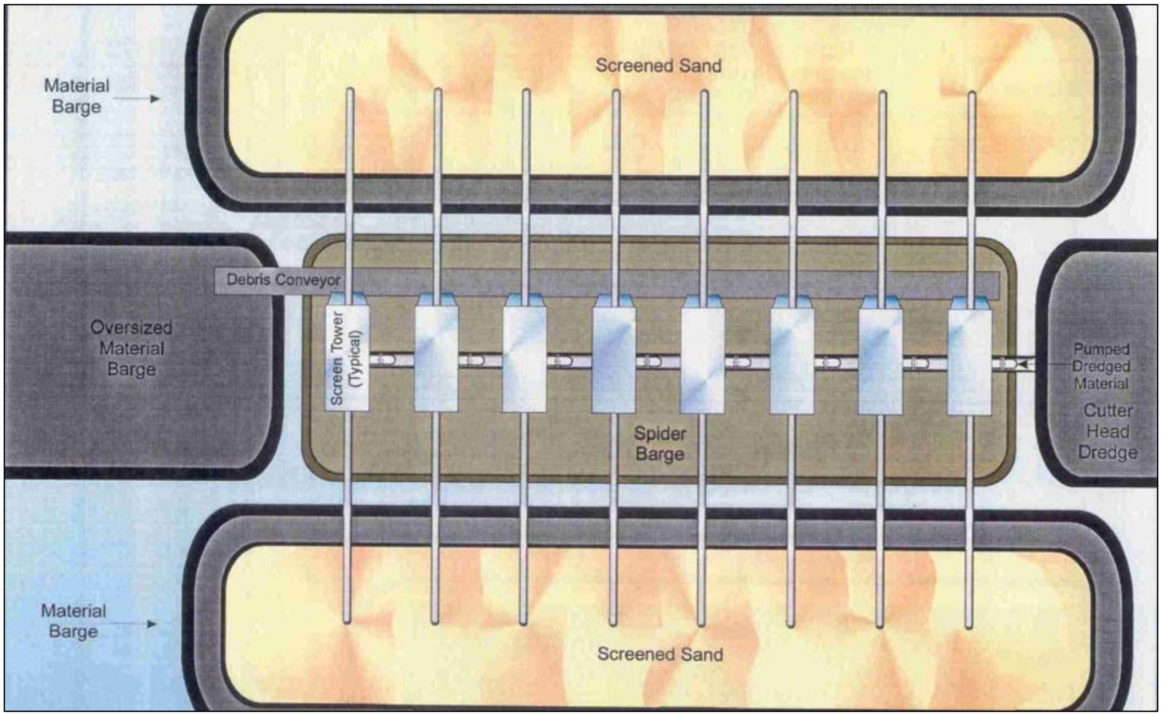

Figure 3-13. Static screening onboard the spider barge.

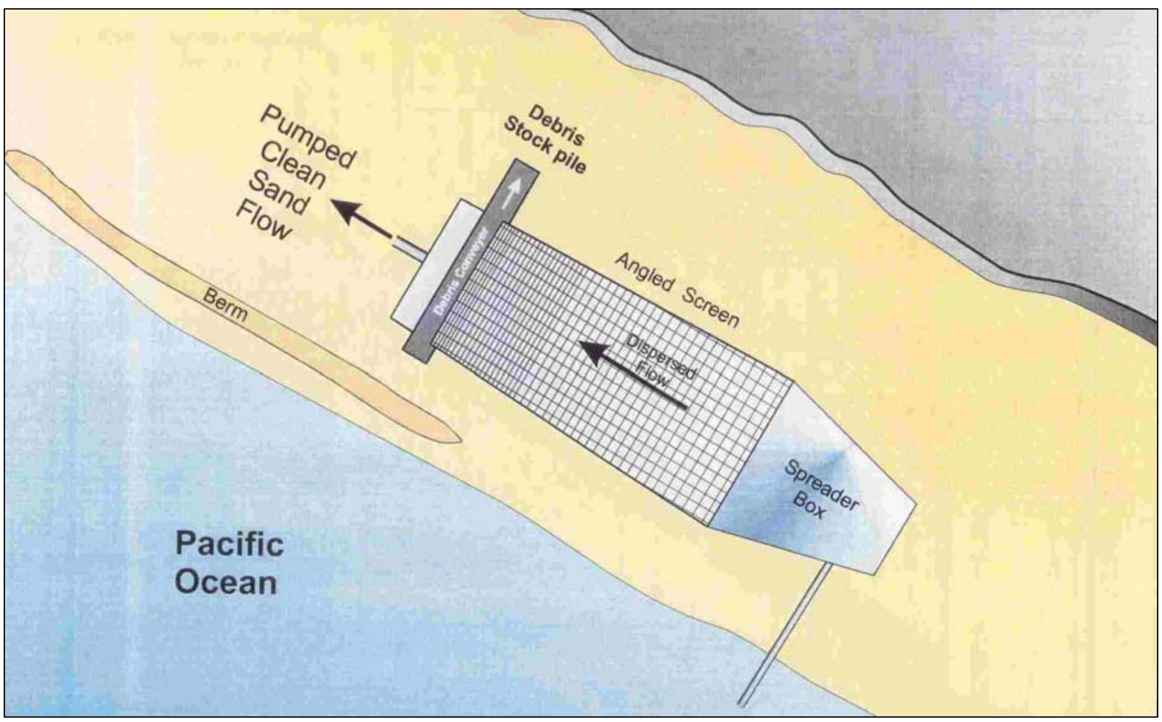

Figure 3-14. Plan view of static screening plant alternative on beach.

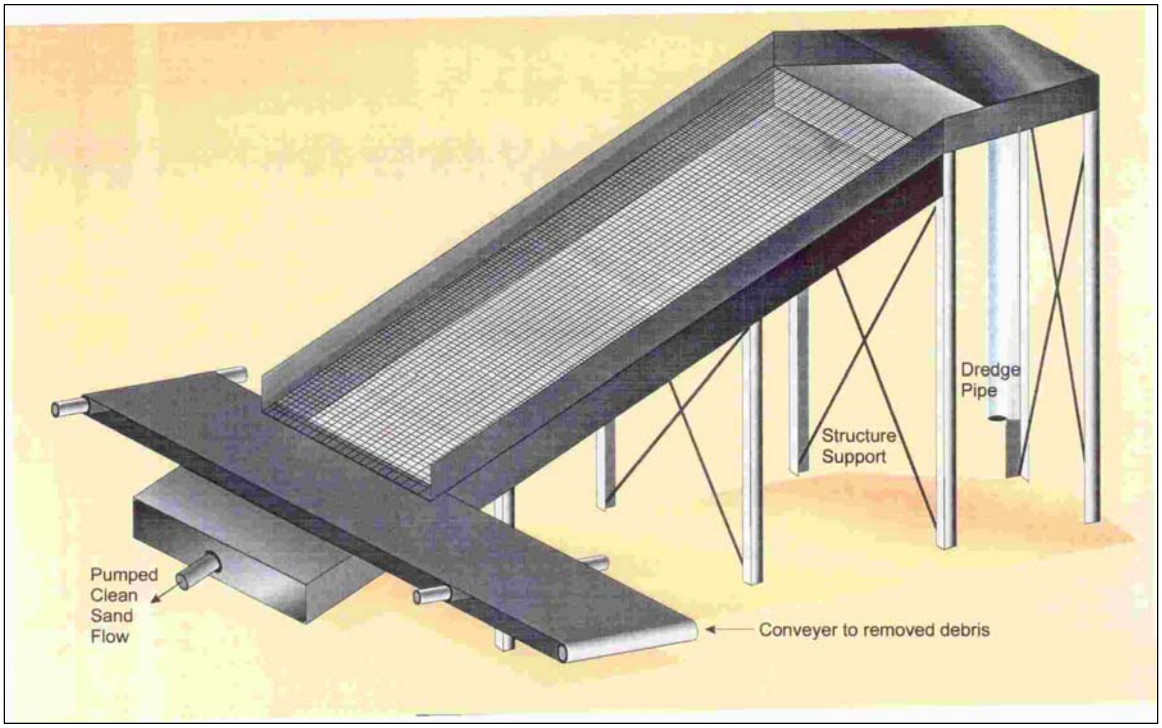

Figure 3-15. Profile view of static screening plant on beach.

3.2.2.2 Trommel Screens

Trommel (or revolving) screens are usually used to separate items from approximately 1 cm to 10 cm (0.4 in to 4 in) in diameter. A trommel screen (Sullivan, 2004) is best described as a rotating, slightly inclined cylinder constructed of heavy wire mesh or punched steel (Figure 3-16). They may be used as a second-stage separator, i.e., after the grizzly, or as a first stage process, depending on site material conditions. Trommels are rugged and require little maintenance (Engineering Research and Development Center, 2001). They remove small debris and are useful in sediment processing to capture objects that could damage later stage processing equipment. These revolving screens are also used for coarse screening where disintegration and washing of material are required. Mining applications include sizing phosphates, gravel and crushed stone, and removing coarse material from the feed on gold and tin dredges (Cummins, 1973). A beach sand mining operation in Florida uses a trommel with a diameter of 2.4 m (8 ft) that is 9-m long (30-ft long). Equipped with polyurethane screening, this trommel separates debris larger than 5 mm (0.2 in) from a 45-percent solids (by volume) slurry that produces 1200 tons of sand per hour. The trommel was also included in the Southwest Division Naval Facilities Engineering Command (1997) report as a technologically viable alternative for beach operations.

Figure 3-16. Trommel (or revolving) screen.

3.2.2.3 Vibrating Screens

Screening of finer particles in the sand and gravel industry is usually accomplished by vibrating screens as opposed to stationary ones. Screens consisting of woven wire have openings that include square or rectangular shapes, while the scope for plate screen (metal alloys, rubber, or urethane) openings encompasses a wider variety of shapes (Figure 3-17). The flat screening surface (with horizontal or inclined attitude) is generally vibrated at high frequencies with low amplitudes. Rectangular in shape, these screening surfaces have side walls to direct material flow and it is not uncommon to see single-, double-, or triple-stacked screen configurations. Variables that affect the vibrating screen's efficiency include the rate and size of feed, percentage of undersized particle present, intensity and direction of vibration, slope and area of screen surface, and screen opening size (Mallory and Nawrocki, 1974). Southwest Division Naval Facilities Engineering Command (1997) also states that "the vibrating screen plant is large, noisy, requires additional power, and is expensive."

In the San Diego project, one alternative investigated was a vibrating screen processing plant on the beach to handle the hopper dredge-pumped slurry (described in the previous section). This alternative was determined to be technologically viable and would have required 6 to 8 separate vibrating screen units with deck areas of 7.5-m long and 3-m wide (25-ft long and 10-ft wide). Any perceived concern of military munitions being subjected to the high-frequency vibration (and subsequent ignition or blast potential) was not addressed in the report.

Figure 3-17. Vibrating screen.

3.2.2.4 Spiral Classifier

Spiral classifiers are typically used in the gravel or grinding industries to dewater and separate material of various sizes. In sand and gravel processing as shown in Mallory and Nawrocki (1974), a spiral classifier or screw washer receives the tank-discharged sand and elevates it by using a rotating screw (Figure 3-18). This mechanical churning action agitates the sand and washes fine materials from it. Flush water aids in washing the fines from the sand and transports the fines down into a flared tub where it is discharged over weirs. Additional water is fed into the bottom of the tub (that can be adjusted) to form a rising current to carry material over the weirs. The water feed rate (and resultant current) determines the minimum density of materials flowing over the weirs. The spiral classifier is also included in Southwest Division Naval Facilities Engineering Command's (1997) report as a technologically viable alternative for separation of munitions on the beach.

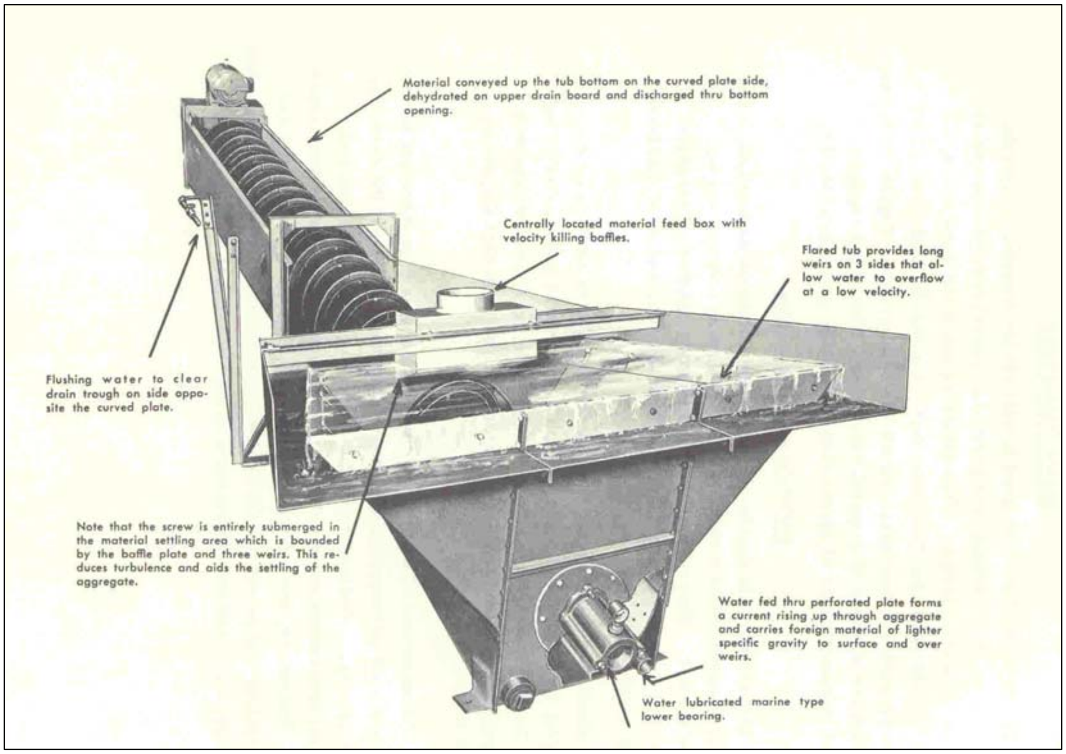

Figure 3-18. Spiral classifier.

3.2.3 Density Separation

3.2.3.1 Hydrocyclone

Hydrocyclones are a well-established tool used primarily in the mining and mineral processing industry to physically separate materials of different densities including but not limited to particles (or sediments). They contain no moving parts and are defined by Svarovsky (1984) as "static separators based on centrifugal separation in a vortex generated within a cono-cylindrical body." The slurry to be separated enters tangentially as a feed flow into the upper (cylindrical) pan of the hydrocyclone where it transverses along the outerwall. The slurry then increases in angular velocity along the length of the hydrocyclone, generating a centrifugal force that causes the larger particles to be forced against the outer wall. These larger particles then exit the hydrocyclone in a low-water mix called the "underflow." The circular motion of the fluid inside the hydrocyclone initiates a centrally located low-pressure vortex about which the primary flow rotates. This vortex is connected to the top of the hydrocyclone at a "vortex finder." Because the coarser particles are centrifugally forced to the outside of the hydrocyclone, the lighter, smaller particles become closer to the vortex flow as the primary flow progresses down the conical-shaped hydrocyclone. Once in the vortex, the smaller particles and most of the water exit the hydrocyclone in a high-water content mix called the "overflow." Figure 3-19 is a schematic of a hydrocyclone showing locations of feed flow, underflow, and overflow as well as internal vortex and centrifugal flow.

Larger diameter material is usually prescreened from the slurry before entering a hydrocyclone. Hydrocyclones separate silt and clay (or heavy metals) from sand material. Clean sand is discharged from the bottom of the hydrocyclone (underflow) and the silt and clay fractions (overflow) are discharged on the upper end (Engineering Research and Development Center, 2000). Hydrocyclones operate best when a constant feed (flow and density) is supplied. However, performance parameter limits the effectiveness of hydrocyclones being connected directly to a hydraulic dredge discharge line because of the inherent fluctuations of dredge operations and the resulting slurry characteristics.

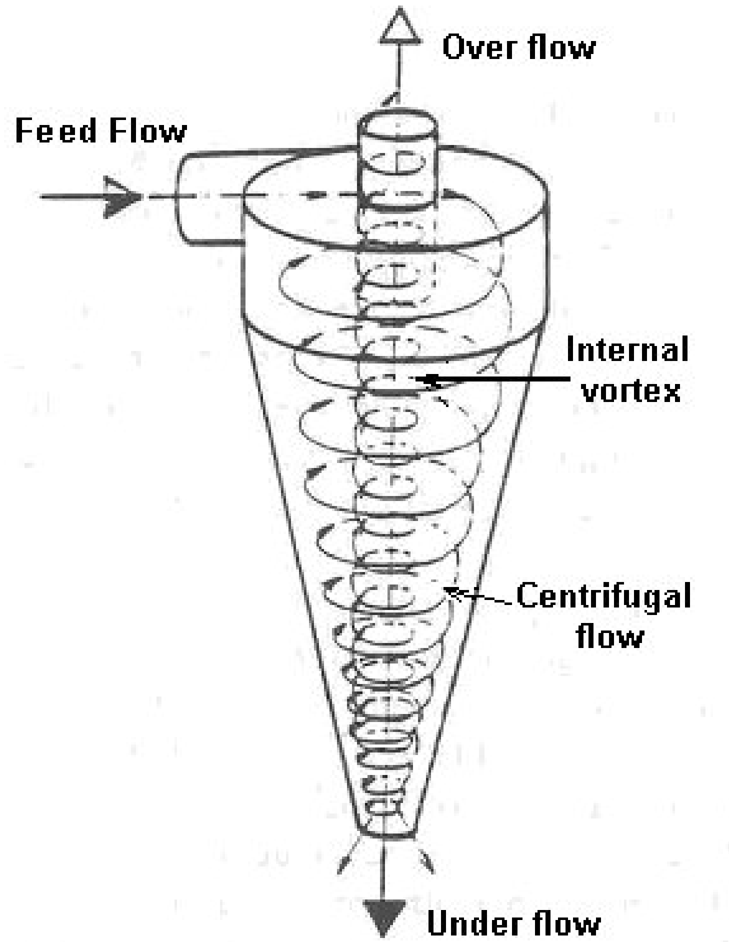

Figure 3-19. Hydrocyclone schematic.

3.2.3.2 Settling Basin/Sluice Box

A settling basin or a sluice box is a hydraulic separator where a basin is constructed in the flow line. The basin's physical geometry is designed to increase the flow area, causing the velocity of the slurry to be reduced, and as a result of the lower velocities, all particles with a specific gravity greater than or equal to the lightest (or smallest) ordnance will settle out. Sand and silts would remain in suspension at the reduced velocity and exit the basin (Southwest Division Naval Facili-

ties Engineering Command, 1997). A settling basin at the beach was included in the Southwest Division Naval Facilities Engineering Command (1997) report as a viable alternative, but comments were cited that the large flume size would prohibit mobilization and that the beach area was not large enough to accommodate the flume. The preliminary estimates indicated the need for a flume size of 50 to 100 m (164 to 328 ft) long and 3 to 5 m (10 to 16 ft) wide. It also indicated that the costs were high and that there was no assurance that the basin would screen out all ordnance.

3.2.4 Magnetic and Electromagnetic Technologies for Identification, Discrimination, and Separation

With respect to existing capabilities, technologies available for identification, discrimination and separation include magnetic, electromagnetic, acoustic and electro-optical sensors, and several experimental efforts that have attempted to develop integrated platforms with multiple sensors. The capability of separating munitions from a dredging slurry would require multi-sensor systems capable of independently measuring different target (UXO) characteristics in difficult environmental conditions. Two possibilities were selected during the first phase of this project for use in identification and then separation of UXO from a slurry: (1) magnetometer sensors placed on the discharge pipe, and (2) an electromagnet (as used in the construction industry) placed at the end of the discharge pipe to supplement mechanical separation. Subsequently, it was concluded that neither of these two theoretical applications could provide assurance that UXO would be removed from the dredging slurry.

3.2.4.1 Technology Survey Efforts

The underwater military munitions location and separation problem is complicated by a wide range of magnetic and non-magnetic targets of various sizes, often shallowly buried or obscured by biological growth. With respect to existing capabilities, technologies available include magnetic, electromagnetic, electro-optical, acoustic and chemical sensors, and several experimental platforms that have or are attempting to develop integrated platforms with multiple sensors. Munitions target characteristics measured by a single underwater sensor (acoustic, electromagnetic, or optical) are not currently sufficient to unambiguously distinguish detected military munitions targets from debris or many natural underwater structures (e.g., rocks, coral, or magnetic anomalies) whether they are buried in sediment or entrained in a dredge slurry. An underwater munitions survey capability requires multi-sensor systems capable of independently measuring different target characteristics. While various systems have been successfully used to detect buried munitions on land, doing so in freshwater and marine environments is a more difficult issue to resolve. Compared to land-based systems, not only are the requisite sensitivity and resolution issues a requirement for successful detection of munitions targets, additional problems relating to the high rate of false positives are magnified when attempting to characterize sediments with respect to munitions. Geospatial information issues relating to targets are also more difficult to obtain when deploying a sensor in bodies of water to detect munitions that are on the sediment/water interface or buried in the sediment. Detection systems tested have had limited success with regard to buried submerged targets. Several research and development efforts relating to the development of capability to detect, locate, and characterize military munitions in an

underwater environment are in development. No off-the-shelf sensor or combination of sensors currently exist that can detect and map military munitions under all field conditions. The Department of Defense Strategic Environmental Research and Development Program (SERDP) has and continues to fund projects for site characterization and remediation technologies for munitions-contaminated underwater sites.

3.2.4.2 Magnetometer Sensor Placed on Pipe

One would expect to find that most entrained military munitions are ferrous. However, even if the military munitions do not have a ferrous content, metal detectors can still be used to identify aluminum, brass, copper, stainless steel, titanium, etc., and therefore military munitions containing these metals.

With respect to the use of sensors for capability in support of the in-situ separation effort of munitions, one option might be as a quality assurance measure. Specifically, to place a magnetometer(s) on the discharge line to detect, identify, and possibly redirect ferrous materials, larger than 20 mm that may pass through a section of non-ferrous pipe inserted in the discharge pipe. However, the sensor selection might require prior knowledge of the range of ordnance items at the project site that has a ferrous content (usually the case). For example, magnetometer(s) could be placed in a gradiometer mode at 90-degree intervals around the pipe at four or more locations. This is assuming a diameter smaller than the 36" cutterhead suction pipe where the maximum flow rate is 30 ft/sec. Four magnetometers placed around the pipe would allow a practical sampling space by dividing the 360 degree pipe circumference into four 90 degree intervals. The criteria for magnetometer(s) selection were based on the smallest UXO of concern (20 mm), the specific gravity of the largest particles in the slurry output, the minimum flow necessary to keep the particle in suspension, the sample rate of the magnetometer, and the processing speed of the logic circuit. When munitions are detected in the flow, the magnetometer signal might be used to trigger a switch that could redirect the flow to avoid the main screening technologies (such as physical screens) to an area designated for military munitions-contaminated material. This would, however, require a second complete processing train to handle the diverted flow and would also require the ability of the logic circuit and some type of Y-gate in the pipeline to react quickly enough to divert an identified piece of ordnance. Currently, the most feasible application of electromagnetic detection technologies to an in-situ separation process appears to be limited to providing a quality assurance statement concerning the actual passage of military munitions through the discharge line before or following any separation screening capability.

Magnetometers can detect ferrous items such as iron, nickel, cobalt, and their alloys. The magnetometer measures the magnetic field component along the axis of its core and must be oriented with the field if the total intensity is to be measured. The two major dominating classes of magnetometers are fluxgate and cesium vapor. The goal for the detection limit of an initial capability would be to detect and characterize a 20-mm projectile moving in the slurry discharge pipeline at the normal dredge production rate. This capability has not been demonstrated. The cost of the magnetometers varies by type, fluxgate or cesium vapor, and by the magnetometer sampling frequency. Selected vendors of magnetometers are Forester, Geometrics, Magnatrak, Schiebel, and Schonstedt.

Characteristics of magnetic sensors are shown in Table 3-3.

Table 3-3. Technical aspects, pros, and cons of magnetic and electromagnetic sensors for detection.

Types	Examples	Technical	Pros	Cons
General		Potential search rate of 10 to 50 acres per day possible with towed magnetometers on large targets. Dive team can search 0.5 to 1 acre per day under favorable conditions.	Can provide information on range and location of buried metallic targets, as well as information about target size and shape. Effectiveness not degraded by particulates, encrustation, bubbles, etc.	Interference from navigation and communications equipment. Only ferrous contamination leads to false positives (alarms). Non-ferrous metallic objects do not cause alarms. GPS required.
Magnetometers	Total Field Magnetic Sensor; cesium vapor magnetometer; Scintrex/ Geometrics/ Varian Inc.; Single Axis Fluxgate; Geometrics, Marine Magnetics, J. W. Fisher, Raytheon, Polatomic, and GEM	Targets are indicated by peaks and troughs in a background-measured signal in nanoteslas.	Location and size information. Some equipment provides digital record vs. analog signal only.	Magnetic targets only. Range less than 12 feet. Subject to temporal magnetic field variations. Detection range is highly dependent on ferrous mass. GPS required. Platform must be non-conducting.
Gradiometers	Fluxgate magnetic sensors (Foerster 4.021 FEREX/MK 26 Ordnance Locator); Superconducting Quantum Interference Device SQUID sensors.	Gradiometers do not have to be arrayed, nor do they have to use total field sensors	Potential range with SQUIDS tens of meters for large ordnance; order of magnitude less with fluxgates. Some equipment provides digital record vs. analog signal only.	Magnetic targets only. Precise GPS required. SQUIDS require cryogenic fluid.
Electromagnetic Induction	J. W. Fisher PULSE Handheld and towed. Geophex GEM3. Geonics EM-61. Vallon MW 1630B/MK 29	Active electromagnetic pulse (only in time domain sensors) creates eddy currents in target; collapsing magnetic field in target results in a measurable signal. GEM3 uses CW signals.	Detects both magnetic and nonmagnetic metallic targets. Some equipment provides digital record vs. analog signal only. Ongoing research on discrimination.	Relatively short range. No information on magnetic moment. Platform must be non-conducting. Relatively High Power requirement.

Types	Examples	Technical	Pros	Cons
Still in the R&D development	Magnetic Tensor Gradiometers, including superconducting.	A variation on multiple fluxgate magnetometers separated by a fixed baseline. DERA Malvern, Navy, Quantum Magnetics, and IBM.	The future promise of precise 3-D localization with superconductors.	Cryogenic helium or nitrogen required for high performance superconducting versions.

3.2.4.3 Electromagnetic Separation

A conveyer belt is often used to transport dredged material between material sorting and storage points. It could be useful to separate military munitions by using an electromagnet to move munitions along with other metal debris to a second conveyor belt for deposition behind protective barriers, which would provide a safety barrier for personnel and equipment that would be responsible for the final disposition of separation and disposal of the military munitions.

This concept (unproven) envisions a powerful electromagnet removing ordnance out of the discharge flow, holding it against a moving conveyor belt oriented 90 degrees to the flow of the discharge and moving the ordnance some distance laterally until it is physically scraped off the belt and deposited in a pile with other oversize material (with adequate blast protection surrounding the drop zone). This process is explained further in Section 3.4.4 describing the San Diego site visit. One product vendor is Shields Company Magnetics (http://www.shieldscompany.com) that supplies magnets for conveyors and separation. A listing of available vendors are listed at http://www.thomasnet.com/products/conveyor-magnets-49491202-1.html

3.2.5 Other Screening Methodologies

3.2.5.1 Geotextile Tubes for Retaining Fill on-the-Beach Prior to Military Munitions Sweep

A method for military munitions removal by placing a geotextile barrier to prevent dredging material from running off the beach was discussed in the San Diego Channel Report (Southwest Division Naval Facilities Engineering Command, 1997). After the slurry was to be delivered to the beach, a military munitions sweep was proposed for use in detection and removal of ordnance. A significant drawback was the requirement to use heavy machinery to move the beach material to allow for a complete sweeping capability for military munitions. This method also included liabilities associated with the known intent of placing military munitions on a public beach for any reason, and the evaluation that the method would not be expected to be 100 percent efficient.

3.2.5.2 Rotating Flow Vane

A rotating flow vane would use angular momentum to separate the larger articles, including military munitions, from the pipeline flow. At the end of the rotating flow vane, the pipe would decrease in size and an opening would be present so that the heavier articles would be able to fall through this gap. This method is unlikely to be 100 percent efficient, and some of the ordnance

would pass through the flow vane and inadvertently be placed in beach renourishment sites (Southwest Division Naval Facilities Engineering Command, 1997)

3.2.5.3 In-Line Debris (Rock) Box

The in-line debris box (commonly called a rock box) is a section of pipe that has a larger cross-sectional area designed to cause a reduction in slurry velocity. This reduction causes the "heavier" material to fall out of suspension and stay in the box. The San Diego Channel Report (Southwest Division Naval Facilities Engineering Command, 1997) considered that "the primary disadvantage with this alternative is that large quantities of heavy particles will fill any practical size of in-line box. Also, it is considered likely that some ordnance would pass through the box. One option included the addition of screens in the pipeline at the debris box to ensure that particles fall out of the pipeline flow. Although this idea would prevent ordnance from passing through the dredge, it will have the same problem described above, and the screens will likely clog, even if angled to encourage the particles to fall away."

These performance parameter concerns were realized in the Eagle River Flats project with the "expander box." Even though it was effective in excluding ordnance from the pump, it eventually failed because of vegetation and woody debris clogging the suction or lodging in the pump eye. Neutrally buoyant wood and lighter aluminum pieces would not always drop out into the expander box. When a coarse screen was installed inside the expander box, the screen "quickly plugged, crippling the dredge in a matter of minutes" (Walsh and Collins, 1998).

Another attempt to use a rock box with screen was with the 762-mm (30-in) cutterhead dredge, *Bill James*, working on the Sea Bright project. The rock box, designed with a volume of approximately 0.8 m^3 (1 yd^3) and a bar screen with 38 mm (1.5 in) openings, was installed on the dredge's suction line. This rock box was also equipped with a "remote-flushing" capability that allowed the rock box to be opened (emptied) by remote control. Use of the screened rock box was discontinued because of its impact on production caused by clogging and operational problems (Personal Communication, Rick Smith, 2004).

Another in-line separation method, although not based on the velocity reduction concept of the rock box, is that of using a perforated pipe on the slurry discharge pipe situated over a barge that terminates into a "rock basket" (Southwest Division Naval Facilities Engineering Command, 1997). This method was successfully used for screening small rocks greater than 38 mm (1.5 in) for a project in Florida using Great Lakes Dredge and Dock's hopper dredge, *Long Island*. Slurry was discharged into the barge through the pipe perforations with the rocks rolling down to the end of the pipe and being retained in the rock basket. It was not known what the percentage of oversized material was for this project. While the San Diego Channel Report (Southwest Division Naval Facilities Engineering Command, 1997) considered this alternative to not be technologically viable onboard the dredge, *Stuyvesant*, under the existing contract, it considered this technique viable for use on other hopper dredges with less constrained deck conditions than the *Stuyvesant*.

In April 2002, during the creation of a Berthing Wharf at Naval Air Station, North Island, Coronado, CA, pumped 500,000 yards of sand was pumped through a rock box to create a small island "25-acre inter-tidal/sub-tidal habitat site" (Figure 3-20 and Figure 3-21). Live small-arms rounds were removed from the rock box on a few occasions (Navy Region Southwest, Naval Base Coronado, 2004)

Figure 3-20. Dredging at Coronado Island.

Figure 3-21. Discharge and rock box at Coronado Island.

3.2.5.4 "Lu Lu" Whirlpool

The "Lu Lu" whirlpool method consists of creating a whirlpool in a silo that has a physical screen basket. The dredged material would be pumped to the top of the silo into the screen basket, and the screened material would then be pumped out of the bottom of the silo through a pipeline onto an oversized area. This method requires a large screen basket, and when the basket is full, ordnance and other oversized material are expected to over-top the screen. The basket was evaluated to require cleaning and maintenance to empty the oversized material, which would take significant time and cost, and would impact production rates (Southwest Division Naval Facilities Engineering Command, 1997).

3.2.6 Applicability of Transferable Parameters for Screening Devices

Separation technologies for hydraulic dredges were reviewed for the following parameters: maximizing elimination of military munitions from the discharge, excluding threshold military munitions from entering the dredge, optimizing production rates, minimizing capital and operating costs, and maintaining an emphasis on risk reduction.

The results of the review indicated that the proposed screening technologies previously proposed for a demonstration project would exhibit the greatest applicability to the broadest range of dredging operations for the Army and Navy. Performance parameters established from the demonstration would be transferable between dredge sizes and types (cutterhead and hopper). The discharge screening device (static polyurethane screen) production parameters would transfer

directly from a 30-cm (12-in)-diameter dredge to the 90-cm (36-in)-diameter dredge. Because of the similarities between the slurry (percent solids and slurry velocities) flowing into a hopper and that coming out of a cutterhead pipeline, the total dredge discharge rate of the hopper dredge's dragarm or cutterhead dredge hydraulic circuit would determine the number of "turn-key" screening devices required to handle the material. In other words, demonstration screening performance parameters established for the 30-cm (12-in)-diameter pipeline flow rates could be applied to larger dredges (larger discharge pipeline diameters) if the larger dredge's discharge is divided into similar flow rates as those evaluated during the demonstration and applied to the same screening area.

However, suction end (screening) production rates will not be as directly applicable (from the demonstration cutterhead dredge to larger cutterhead dredges) as their performance parameters would be a function of the dredge and cutterhead type, size, screen size, military munitions threshold, and sediment to be dredged. However, these parameters are transferable for similar conditions and can differ in accordance with the number of physical variables and the options under consideration by the project manager.

3.3 EXPLOSIVE SAFETY REVIEW

3.3.1 Basic Ordnance Properties

The occurrence and amount of ordnance encountered in the marine/dredging environment would presumably depend primarily on the proximity of the dredging area to current or former DoD installations in the United States. However, if the dredging area was used as a transit area for ordnance, this possibility should also be considered. For example, if a channel was used to transport small-arms ammunition during WWII, then ordnance from that time period (such as MK II hand grenades) could be expected in the area to be dredged. Former military ranges, ammunition loading facilities, and areas subjected to live warfare and/or bombing would be the areas most likely to exhibit military munitions problems associated with dredging.

The fragmentation and blast danger areas directly depend on the type and amount of explosive contained in the ordnance. For example, a 20-mm, high-explosive projectile weighs 132 grams, of which 82 grams is the tetryl explosive filler. Table 3-4 gives a breakdown of some of the ordnance types expected to be encountered in dredged material and therefore mentioned in this report.

Table 3-4. Summary of ordnance previously encountered. (Naval EODTECHDIV, 2004)

Ordnance	Length	Total Weight	Net Explosive Weight	Minimum Fragment Distance (m)	Maximum Fragment Distance (m)	Blast Danger Area (m)
20-mm HE	83 mm	132 g	82 g	66	443	6
37-mm AP	107 mm	753 g	N/A	N/A	N/A	N/A
40-mm AA	184mm	930 g	90 g	74	526	7

Ordnance	Length	Total Weight	Net Explosive Weight	Minimum Fragment Distance (m)	Maximum Fragment Distance (m)	Blast Danger Area (m)
2.75 Stokes mortar	362 mm	5.70 kg	1 kg	115	1030	18
81 mm	432 mm	4.27 kg	1 kg	115	1030	18
MK II grenade	114 mm	580 g	28 g	66	443	6
10-in projectile	823 mm	235 kg	32.75 kg	195	1,585	52
500-kg Japanese bomb	2.35 m	509 kg	242.90 kg	275	1,943	103

Figure 3-22, Figure 3-23, Figure 3-24, and Figure 3-25 give representative pictures of various pieces of ordnance found.

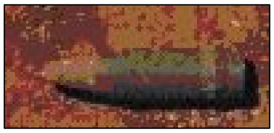

Figure 3-22. 20-mm projectile.

Figure 3-23. MK II hand grenade.

Figure 3-24. Stokes mortar.

Figure 3-25: 81-mm mortar.

The most sensitive part of any ordnance item is located within the fuze. Fuzes are broken down into family types by using a type-by-function classification system. Some examples include point detonating (PD), mechanical time (MT), powder train time fuze (PTTF), and electronic time (ET). Each family type has its own specific as well as general safety precautions. To elaborate on the above examples, a PD fuze requires impact to function after it has been armed. An MT fuze requires the elapse of a prescribed time to function. Because of all the different fuze types, it would be impossible to make generic statements such as “vibration will not cause initiation” (ORDATA, 2002).

Ordnance placed into the marine environment will eventually corrode and disintegrate with time, releasing the energetic material (munitions constituents) that are contained within the body and/or explosive train of the ordnance into the environment. The rate of corrosion can vary with the thickness of the shell casing, location of the piece of ordnance (buried or unburied), the ambient temperature and salinity, the amount of biofouling on the surface of the ordnance, and the amount or absence of energy available to physically transport pieces of military munitions from place to place. Fuzed rounds may only be considered safe when any part of the explosive train is disrupted by mechanical, chemical, or other events that would prelude proper operation of the fuze. Although it is recognized that prolonged submersion will probably affect the operation of a fuzed munition, any round that is still intact (fuzed or unfuzed) should be considered an explosive hazard until properly disposed of by trained personnel. All explosives are actually comprised of a fuel and an oxidizer, and being submerged in water will not necessarily prevent an explosive reaction involving a particular piece of submerged ordnance, even if the shell casing is breached. Given the thickness of many of the shell casings on rounds used in the past, it would be expected that a particular round could maintain its integrity (and explosive capability) for decades or centuries while lying on the sediment/water interface of a body of water.

3.3.2 Explosive Safety Reviews

Little documentation exists to describe the approach to explosive safety plans. As stated in the Ordnance Reconnaissance Study for the Sandy Hook to Barnegat Inlet, New Jersey, Beach Erosion Control Project (Pope, Lewis, Welp 1996), once ordnance was found, contracted UXO specialists were called. Other project plans reviewed did not describe any explosive safety reviews.

3.3.3 Regulations

If military munitions have been found in the area to be dredged, appropriate precautions must be considered. As established in DoD Directive 6055.9, a basic tenet of the DoD explosive safety policy is to limit exposure of the minimum number of people to the minimum amount of explosives for the minimum amount of time, consistent with operational requirements. For Navy projects, if the chances of encountering military munitions are likely, an Explosive Safety Submission (ESS) must be made in accordance with Naval Ordnance Safety and Security Activity INSTRUCTION 8020.15, "Military Munition Response Program Oversight." An important part of the ESS discusses ways to reduce the risks associated with encountering military munitions. Risk reduction normally consists of avoidance, protective works, and providing distance between the anticipated area of military munitions detonation and personnel. Coordination with the Department of Defense Explosive Safety Board (DDESB) may be required when the project location, the project objectives, and the military munitions list is determined; however, especially if the purpose of removing ordnance was for the transfer of property.

3.3.4 Dredging Safety and Survivability Plan

A Dredging Safety and Survivability Plan for removing unexploded ordnance during dredging operations should be considered if military munitions are anticipated during the dredging operations. This safety plan should describe a general approach that can be applied toward all dredging operation procedures that might involve discovered and undiscovered unexploded ordnance. The Safety and Survivability Plan should follow specific guidelines designed to provide project managers information to develop options for removing military munitions from dredged material.

The Dredging Safety and Survivability Plan should include a section on explosive safety similar to those required for land-range munitions mapping and safety. This plan should be coordinated with the Army Corps of Engineers Ordnance and Explosives Center of Expertise (Huntsville, Alabama) for Army projects or the Navy Ordnance, Safety and Security Activity (Indian Head, Maryland) for Navy projects and will address safety and contingency issues common to other ordnance and explosive (OE) projects. A brief sample outline of a proposed guideline is provided in the following subsections.

3.3.4.1 Preliminary Assessment

In an actual dredging operation, finding even one piece of ordnance can be a cause for concern. To reduce the probability of that unanticipated occurrence, a Preliminary Assessment (PA) should be attempted. The PA consists of researching the national archives, local newspapers near the dredging site, military records near the dredging site (if applicable), and any other source of potential historical data that might reveal instances of ordnance being found in or near the proposed dredging site. Information found in these sources could be used to base decisions regarding future actions. If there are no historical data regarding the presence of munitions in the area to be dredged, the likelihood of encountering munitions should be considered minimal but not improbable. On the other hand, if munitions have been found in the area to be dredged, precautions should be considered before and during the dredging effort and compliance with an existing agency directive would be recommended in an attempt to reduce the risks associated with en-

countering munitions. Risk reduction normally consists of avoidance, protective works, and providing distance between the anticipated area of ordnance detonation and personnel.

3.3.4.2 Evaluate the Ordnance Fragment Blast Effects

To minimize the potential blast and fragment environment effects that could result from military munitions detonation within the dredge, a technical approach is required. This approach would use an iterative process to evaluate the trade-offs between shielding personnel and critical equipment and/or screening munitions from the dredge. This issue is complex because explosion damage within the dredge is a function of many variables that include the blast and fragment patterns and forces, the density of the surrounding medium, the containment volume and wall strength, the location of the explosion within the dredge, as well as the proximity of the munitions to the wall of a pipe/pump/hull. Initially, a list of munitions that may be found within the dredging area should be developed if prior knowledge is available. A sequence of this evaluation might include the following steps. The first step would be the evaluation of the dredge intake pipe and determination of the dimensions of the largest size of military munitions that could physically be passed into the dredged system. All munitions on the initial list that exceed the physical limits of the pipe will be eliminated from the list of munitions to be evaluated in the iterative investigation. The munitions remaining on the list are now the military munitions of concern (MofC) for this investigation. The MofC are then correlated with the actual physical dimensions of each piece of munition and the potential blast and fragment environment associated with their explosion in water, slurry, and air. The iterative evaluation begins here. From the MofC list, the selection of the munitions with the largest or most powerful blast and fragment environment would be necessary, followed by an evaluation of the potential damage an explosion that this most conservative estimate would impart on the dredge crew. Additionally, it would also be necessary to determine the shielding requirements for safety and damage minimization as well as cost for shielding and damage repair. In parallel, determination would be made of the minimum aperture for screening on the intake with spacing that will exclude the oversize military munitions from entering the dredge. Dredge production rate losses associated with the reduced screen aperture would be evaluated and then the best option between screening and shielding would be selected. If a smaller screen aperture is selected, then another cycle of this iterative process would be evaluated, selecting the MofC associated with the next most powerful blast and fragment environment and proceeding with the iterative evaluation until an acceptable level of safety and shielding is achieved.

Blast effects can be identified through literature searches and knowledge databases, or through numerical modeling effects. Blast effects for munitions in open air are tabulated in DoD explosives safety guidance. Standard methods for calculating the damping effects of barriers are available. However, the effects of underwater detonations or detonations within equipment would have to be individually calculated and/or modeled by experts. Information is not available for in-slurry blasts within a contained area such as a pipe, pump or hull.

3.4 SITE VISITS

3.4.1 Baltimore-Harts Miller Island CDF

A site visit was made in October 2003 to observe procedures associated with the USACE Baltimore District effort involving maintenance dredging and new works using Weeks Marine and a clamshell dredge. The new works areas contained sediment and ordnance dating back to the 18th century. Over 1300 ordnance items were recovered and disposed of during the screening process. 5600 m^3 (7000 yds^3) of debris was generated from the 2.8 million m^3 (3.5 million yds^3) of material dredged. The sediment was disposed of at Harts-Miller Island (HMI), the second largest confined sediment disposal facility in the United States. The process started with the debris being removed from the contaminated site by using mud scows, then being transferred into trash barges for temporary storage. A barge-mounted crane then lifted individual large items out of the trash barges. These items were inspected by ordnance specialists, and once cleared; the items were placed on a separate barge for disposal. The remaining dredged sediment/debris was loaded by crane on an articulated dump truck for transfer to the screening area on the middle dike at HMI. A front-end loader and excavator then dumped the material on grizzly screens with 19-mm (¾-in) square openings (Figure 3-26). The dredged material was sprayed with a high-pressure water jet (Figure 3-27). An ordnance specialist attended the wash-down process, inspecting for ordnance within the dredged material (Figure 3-28). The screening with the grizzly and water jet averaged about 15 minutes per 4 yds^3. The USACE Baltimore District was dealing with several dredging projects containing military munitions.

Figure 3-26. Loading material on a separation screen.

Figure 3-27. Water jet spraying dredged material on screen.

Figure 3-28. Inspecting dredged material for ordnance.

3.4.2 WEDA Conference

Two team members attended the Western Dredging Association's (WEDA) 23rd Technical Conference and 35th Texas A&M Dredging Seminar held 10–12 June 2003 in Chicago, Illinois. WEDA covers North, Central, and South America and is a part of the World Organization of Dredging Association (WODA). This conference attracts domestic and international presentations/exhibits. Applicable topics covered seminars on screening tools, dredging alternatives for delivering sand for beach nourishment, remediation of contaminated sediment sites, etc. During the presentations, Great Lake Dredge and Dock described the current dredging operations using a cutterhead dredge in Umm Qasr, Iraq. As mentioned previously, ordnance was found and removed before the dredging operations began. The final solution for continued production dredging at that site was to weld metal into 3-inch by 3-inch screens on the cutterhead itself.

3.4.3 Louisiana

All team members traveled to two sand and gravel processing plants to investigate methods for potential removal of military munitions from dredged slurry. Members conducted a plant tour of Standard Gravel Co. and B&J Gravel Co. processing equipment at Columbia, Mississippi; Enon, Louisiana; and Warrenton, Louisiana. Sand and gravel mining industries use hydraulic dredges with a 10-inch cutterhead dredge capable of a production rate of around 6000 gal/min. This size of cutterhead dredge is widely used by USACE for navigation dredging and is similar to that size proposed for the follow-on demonstration study and was approximately one-sixth the size of a harbor dredge.

3.4.4 San Diego

A concrete recycler was visited in two different sites in San Diego, California. The major interest for these visits was to gather more information on electromagnetic separation capability. Concrete recyclers use electromagnets after the concrete has been through a crusher to remove the rebar. The rotating vanes of the electromagnet were able to separate the rebar from the conveyor belt and then place the rebar into a separate location (Figure 3-29). This type of technology could have the potential capability to separate munitions from a dredge slurry discharge.

Figure 3-29. Electromagnet at a concrete recycler facility.

4. OTHER TECHNICAL ACCOMPLISHMENTS

4.1 PROJECT ASSUMPTIONS

The focus of the project was to identify an appropriate technology that would provide in-situ separation of entrained military munitions from dredge material in such a way as to reduce the need for dredge slurry post-dredging separation efforts in a feasible and cost efficient manner. The assumptions that accompanied this project are as follows:

1. It is practically, but not theoretically, impossible to detect and eliminate all military munitions down to the smallest caliber of commonly used ammunition (0.22 cal) with 100-percent confidence from dredge material without seriously impacting dredging production rates, volumes, and costs.
2. An upper bound of military munitions size needs to be defined and applied to the largest military munition that can pass through the suction head, through the pump, and through the discharge screening area.
3. Munitions that are larger than the largest passing piece of ordnance (see (2) above) would out of necessity need to be left on the seafloor or be removed by some other means.
4. The issue of munitions separation from dredge material has to be considered in the context of separation of all other types of debris entrained within dredged material, especially if the selected technology is dependent on separation by size. The issue is one of not only separating the munitions from the sediment slurry but also one of separating the munitions from the other debris that certainly will be separated along with the munitions.
5. From a perspective of explosive safety, it may only be necessary to separate those munitions that may contain an explosive capability (in this case, 20-mm projectiles are considered the minimum size that requires a separation effort, thus potentially allowing ordnance smaller than 20 mm to pass through the process).
6. As with all issues that deal with military munitions, especially those that have been fired on a range but fail to explode, there is a danger of explosion and possible injury to personnel and/or damage to equipment.
7. Navigational and even remedial (i.e., cleanup/munitions response) dredging with military munitions-contaminated sediment will continue for decades into the future, especially at formerly used defense sites (FUDS) containing wetlands, estuaries, streams, rivers, bays and harbors.
8. If munitions-contaminated sediments are to be destined for beneficial uses and cannot be certified as free from ordnance, there will continue to be liability for compensation for the inability to use the dredge material in a beneficial manner, liability for project delay or a requirement to delay while clearing ordnance, and liability for disposal of potentially hazardous material (i.e., the dredge material containing military munitions).
9. No self-contained, turn-key, commercial off-the-shelf technology (COTS) has been identified internationally or domestically that is capable of in-situ separation of entrained military munitions from dredge material.

10. Only conventional ordnance was considered with regard to military munitions-contaminated sediment.

4.2 PROJECT BOUNDARY CONDITIONS

With regard to any continuing efforts to identify and/or demonstrate promising technologies, the following boundary conditions were identified for consideration. These are listed as follows:

1. Initial proof-of-concept for successful demonstration should be attempted separately before consideration of blast safety engineering for personnel and equipment. Inert shapes should be used in a separation demonstration prior to and separate from efforts to determine the criteria for blast safety for an explosion within the hydraulic circuit of a dredge.

2. Because most of the dredging efforts conducted by USACE in the United States are those using hydraulic dredges, any initial proof-of-concept demonstration for in-situ separation should be conducted with a hydraulic dredge.

3. Because most of the human exposure to military munitions via dredge material has occurred within the context of beach renourishment, any proof-of -concept demonstration should be conducted with predominately sandy material.

4. It would be desirable to use a small, dedicated dredge in a controlled environment to maximize experimental design for in-situ separation proof-of-concept.

5. If the proof of concept demonstration is successful, it should be scaled up to application by using a full-size harbor dredge.

6. The most promising technology identified for in-situ separation of entrained military munitions from dredge material appears to be resident within the sand and gravel mining industry (screening technology).

5. CONCLUSIONS

Conclusions include the following:

1. Dredging is required for various purposes and is increasingly conducted in military munitions-contaminated environments. Evidence exists for the potential for explosions occurring in conjunction with dredging operations and associated delays, costs, and safety issues.
2. Military munitions associated with dredged material is considered an issue of concern for the dredging community in the United States, especially for DoD entities that require dredging operations as part of their harbor/channel maintenance, military construction programs or activities on former ordnance ranges.
3. The extent of the problem is thought to be understated because of contractor reluctance to report entrained munitions, primarily because of the potential for loss of dredging opportunity and/or liability issues that could be associated with potentially responsible parties (usually DoD entities).
4. Six additional previously unknown dredging projects affected by entrained munitions were identified by questionnaire (five of them overseas).
5. Several documented incidences of physical damage to dredges or dredging equipment associated with military munitions in dredge material have occurred.
6. No known deaths or injuries to personnel can be associated with military munitions in dredge material; however, this is still a viable concern.
7. In general, current technology fixes for dredging in military munitions-contaminated sediments appear to be limited to a combination of screening at the suction head for hydraulic dredges and placement on a screen with water fluidization for mechanical dredges.
8. In general, large aperture screens appear to work best on the suction end of a dredge and small aperture screens on the discharge end.
9. The ability to conduct dredging in military munitions-contaminated sediments is currently acquired through extra cost expenditure because of the requirement to commit extra time and resources.
10. Based on surveyed responses, the increased costs of military munitions during dredging operations varied anywhere from an additional $60,000 to $30 million. The delay time varied anywhere from 2 days for simple dredging operations to 4 years on a beach replenishment project that will continue for over 50 years.
11. Magnets and electromagnets to separate ferrous material from dredge material might be considered for use in this application.
12. All ordnance found within dredge material requires the attention of trained EOD personnel.
13. Ordnance has undoubtedly successfully passed through hydraulic dredges in the past and will continue to do so in the future. However, it is impossible to predict which items will do so without detonating; therefore, the assumption is that all dredged ordnance has the potential to cause equipment damage or bodily injury.
14. It is recommended that military munitions that present an unacceptable risk to a dredge

and crew be excluded from entering the dredge, and also that munitions entrained within dredged material be prevented from reaching beneficial use sites, i.e., public beaches.

15. Discovery of military munitions-contaminated dredge sites will undoubtedly occur in the future.
16. Currently, no proven commercial-off-the-shelf (COTS) product was identified that can separate military munitions from dredge material without post-processing.
17. The concept of in-situ separation of military munitions from a dredge material is unlikely to be realized unless an attempt is made under controlled conditions to provide a proof-of-concept demonstration through the use of a dedicated operational dredge.
18. A production dredge under contract will not be useful in providing the support necessary to obtain metrics or to conduct controlled experiments to properly evaluate the capability to obtain in-situ separation of ordnance.
19. Specific information relating to the capability of an explosion to cause equipment damage within a dredge pump or pipeline (hydraulic circuit) is limited or non-existent.
20. Specific information relating to the capability of an explosion in the hydraulic circuit to cause injury or death to dredging personnel is limited or non-existent.
21. Data and engineering evaluations would be useful in developing guidelines to reduce cost associated with the use of a large safety factor to compensate for the unknown safety risk and cost estimating risk.
22. Verification of separation technologies will in all probability be required to gain regulatory agency approval for dredging and beneficial use projects.

6. RECOMMENDATIONS

Recommendations included the following:

1. This project should be continued into Phase II for a demonstration to provide proof-of-concept of the ability to screen out inert shapes using a 12-inch hydraulic dredge. (This recommendation was not accepted).
2. Explosive analysis should be evaluated and numerically modeled to describe an underwater munitions detonation within an enclosed hydraulic circuit similar to that found in a dredge pipeline. (This recommendation was not accepted).
3. A manual should be developed to review and recommend blast mitigation techniques for use when dredging in munitions-contaminated sediments. This recommendation was accepted and resulted in a request to produce a guidance document on the operation of dredging equipment in munitions contaminated sediments.

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APPENDIX A: QUESTIONAIRE

Request for Information On Dredging Activities
Impacted by Unexploded Ordnance (UXO)

Dredging is a vital part of the economic development and maintenance of channels, port and harbors. Past dredging projects have encountered and been adversely impacted by the presence of Unexploded Ordnance (UXO) in the sediment. UXO is defined as an item of explosive ordnance (artillery and mortar ammunition, bombs grenades, etc.) which has failed to function as designed or has been abandoned, discarded, or improperly disposed of, and is still capable of functioning, causing damage to personnel and/or machinery. The U. S. Army Corps of Engineers and U.S. Navy are studying the impact of UXO on dredging activities with the objectives of developing and testing operating guidelines and technologies to mitigate impacts caused by UXO presence. Addition information on this study is available at http://www.estcp.org/projects/uxo/200321o.cfm Response to this questionnaire about your dredging experiences on UXO-impacted dredging projects will help this effort achieve these objectives. All responses will be used to develop a database for the purpose of increasing safety and production during UXO dredging projects. In an effort to increase the number of responses and the comfort level of the responder, we are providing an option through which a respondent's identity will remain anonymous. Answers to these questions can be made anonymously through option #5 below. Please feel free to answer only those questions that you feel comfortable answering. Your assistance will help improve the final product, which will be available on the U.S. Army Corps of Engineers Dredging Operations Technical Support web site at

http://www.wes.army.mil/el/dots/dots.html (scheduled for release in 2004).

We realize you are busy and appreciate the time you take to complete the questionnaire.

There are 4 ways in which you may respond to these questions:

1) Go to TBD web site, type in responses, and then return the questionnaire.

2) Open the attached questionnaire in Word 2000, type in responses to the questions, then email to welpt@wes.army.mil.

3) Open the attached questionnaire in Word 2000, print it, write in responses to the following questions, then fax to:

1-601-634-3151 or 1-800-522-6937 ext 3151

Timothy Welp HC-SD
U.S. Army Corps of Engineers
Engineer Research and Development Center

4) Call 1-800-522-6937 ext 2083 to verbally answer the questions.

If you have any questions regarding this questionnaire, please contact Timothy Welp at welpt@wes.army.mil or call 1-800-522-6937 ext 2083, or 1-601-634-2083. Thank you in advance for your assistance.

Please answer all the questions that you can, and thank you for your assistance.

Name of Organization:

Address:

Name (optional):

Telephone number (optional):

Email (optional):

1. Has your organization been involved with dredging projects that have involved military munitions?

Yes No

2. Do you know of other dredging projects that have involved military munitions?

Yes No

2a. If so, please provide the following information:

Project Name

Project Location

Project Date

Project Sponsor Name

Points of Contact Name(s), telephone or fax numbers, or email addresses

If you answered NO to question 1, please return questionnaire as per instructions above,

If you answered YES to question 1, please complete the following questions. If you have encountered more than one project involving military munitions, please describe the projects separately on the additional forms provided.

3. Project Particulars

Project Name

Project sponsor

Project Location

Name(s), telephone numbers, fax, or email addresses of personnel involved:

4. What type of dredging project was it?

New Work

Maintenance

Beneficial Uses (describe type use)

Mining

5. What type(s) of dredge were used in this project?

Hopper dredge

Cutterhead

Dustpan

Ladder dredge

Other (describe)

Name of dredge

6. What was the size of the equipment (e.g. bucket size, discharge line size, hopper capacity)?

6a. What mode of transportation was used (pipeline, hopper, etc.)?

6b. What was the average production rate ($/cu yd)?

6c. What was the volume of the material dredged during this project?

7. Was the presence of military munitions expected before dredging commenced?

Yes No

7b. What quantity, type, and caliber were expected?

7c. Please explain the reason that military munitions were expected.

8. What was the circumstance(s) that the military munitions were discovered (e.g. caught in the drag head or in placement area, etc.)?

9. What quantity, type(s) and caliber(s) (sizes) of military munitions or “military munitions like items” were encountered?

9a. Please describe the dimensions of the military munitions or munition like items (length, width, thickness)

10. Was the source of the military munitions known?

Yes No

10a. If the reason was known please describe (i.e., old munitions dumping grounds, military action, etc.).

11. Was the dredging operation modified after military munitions were identified?

Yes No

11a. If answered yes, were the modifications procedural in nature (i.e., restricting personnel access to the pump room while dredging, removing military munitions from placement area with Explosive Ordnance Personnel (EOD), etc)?

Yes No

11b. If so, briefly describe

11c. If answered YES, were modifications made to dredging equipment (i.e., screens over drag heads of cutter suction port, density boxes, magnetic devices etc.)?

Yes No

11d. If so, describe in detail (what, and where).

12. What was the type of sediment being dredged?

Gravel

Sand

Silt

Clay

12a. Please list any additional geotechnical descriptors available.

13. What was the average depth of the dredging operations?

<5m 5-10m 10-20m >20m

13a. What was the area of the dredge site?

14. How well did the modifications (procedural and equipment) work?

Well

Average

Poorly

14a. Please explain reason(s) for rating above.

14b. How did the modifications change the production rates?

15. Could you offer any recommendations to make the modifications more safe or efficient?

16. What economic impacts did military munitions have on this project? Please describe.

17. Did any of your dredging personnel receive injuries because of the military munitions?

Yes No

17a. If so, please describe.

18. Was any of your dredging equipment damaged because of military munitions?

Yes No

18a. If so, please describe.

19. How much time was lost because of military munitions? _____ days _____ weeks

______ months?

20. Was the military munitions disarmed, and if so which organization executed the disarming (military unit, sheriff, etc.) and what method was used?

20a. Was the military munitions disposed of, and if so, how was it handled? Where was it disposed of? Who was the organization that handled the disposal?

21. If the dredging contract of this project contained specifications relating to military munitions, could you list them below, or provide them by either email, fax, telephone?

21a. Please list contract specification(s)

21b. or send this information to, or call,

Timothy Welp HC-SD
US Army Corps of Engineers
Engineer Research and Development Center
Coastal and Hydraulics Lab
3909 Halls Ferry Road
Vicksburg, MS. USA, 39180

Telephone 1-800-522-6937 ext 2083, or 1-601-634-2083

Fax 1-601-634-3151

22. Do you know of any literature and/or product information regarding military munitions related dredging that would be of assistance to the study? If so, please list.

23. May we contact your organization for additional information? ___ Yes ____ No

If yes, whom should we contact?

Name ____

Telephone number_______________________________

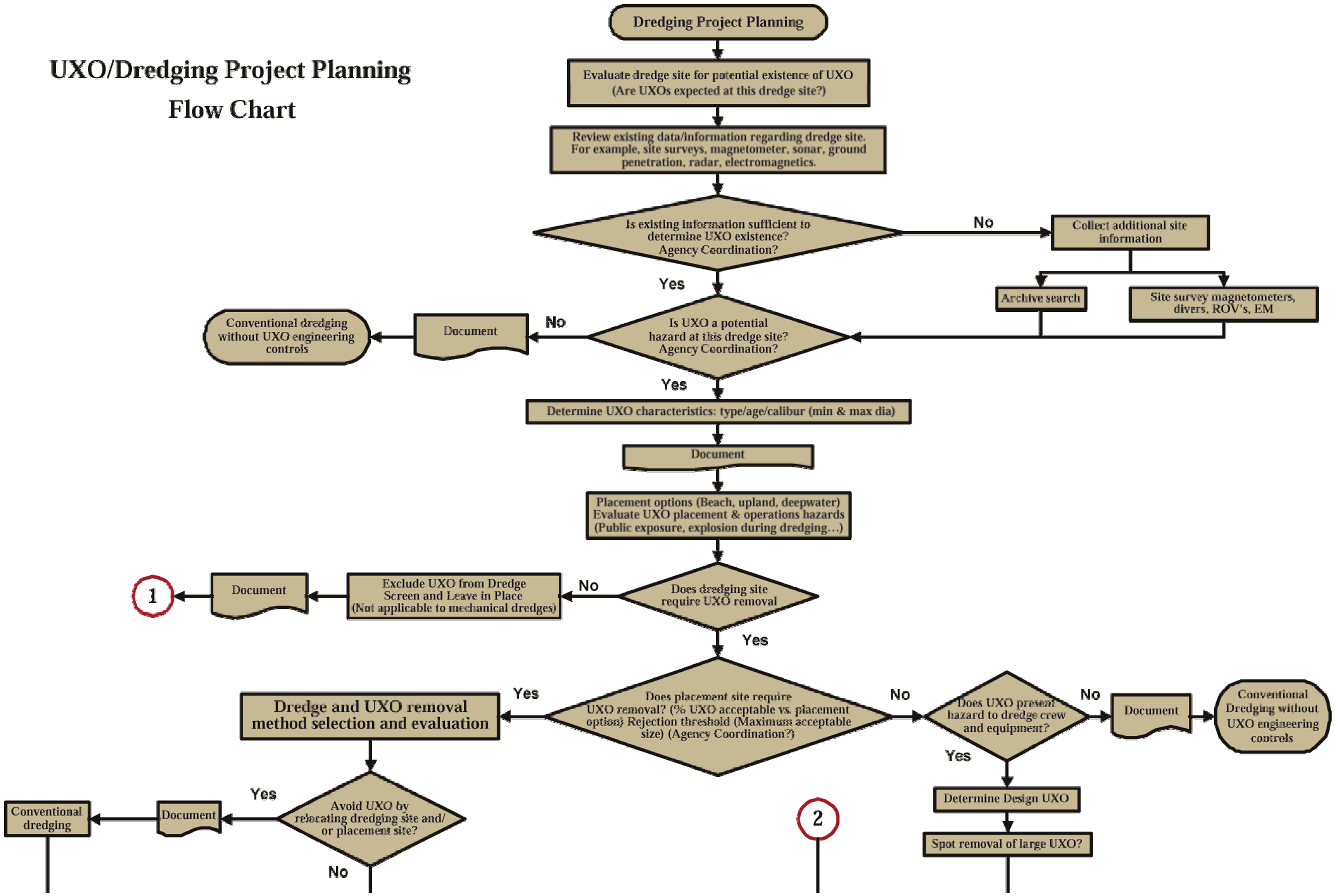
Fax number ____________________________________

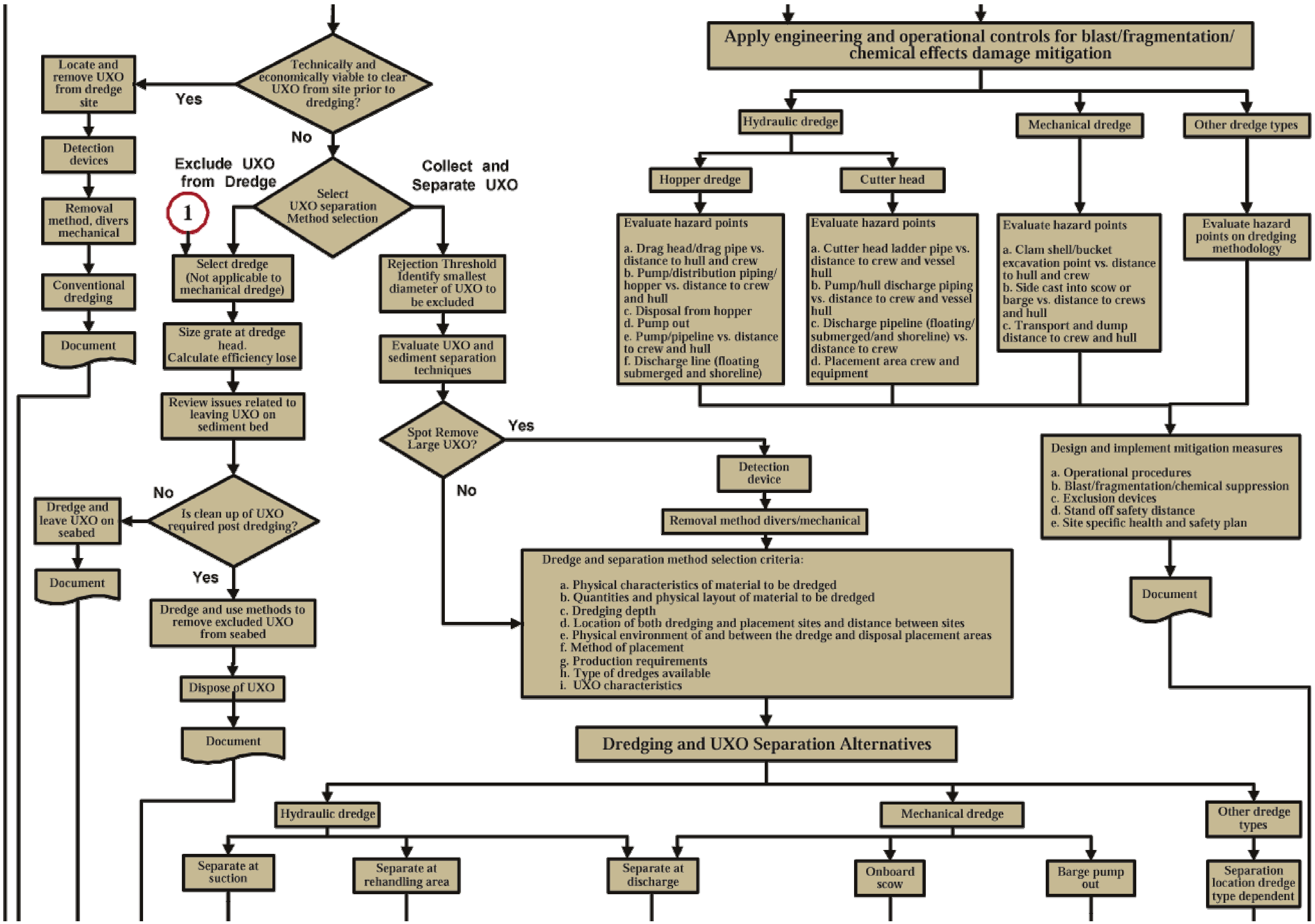
Email address __________________________________

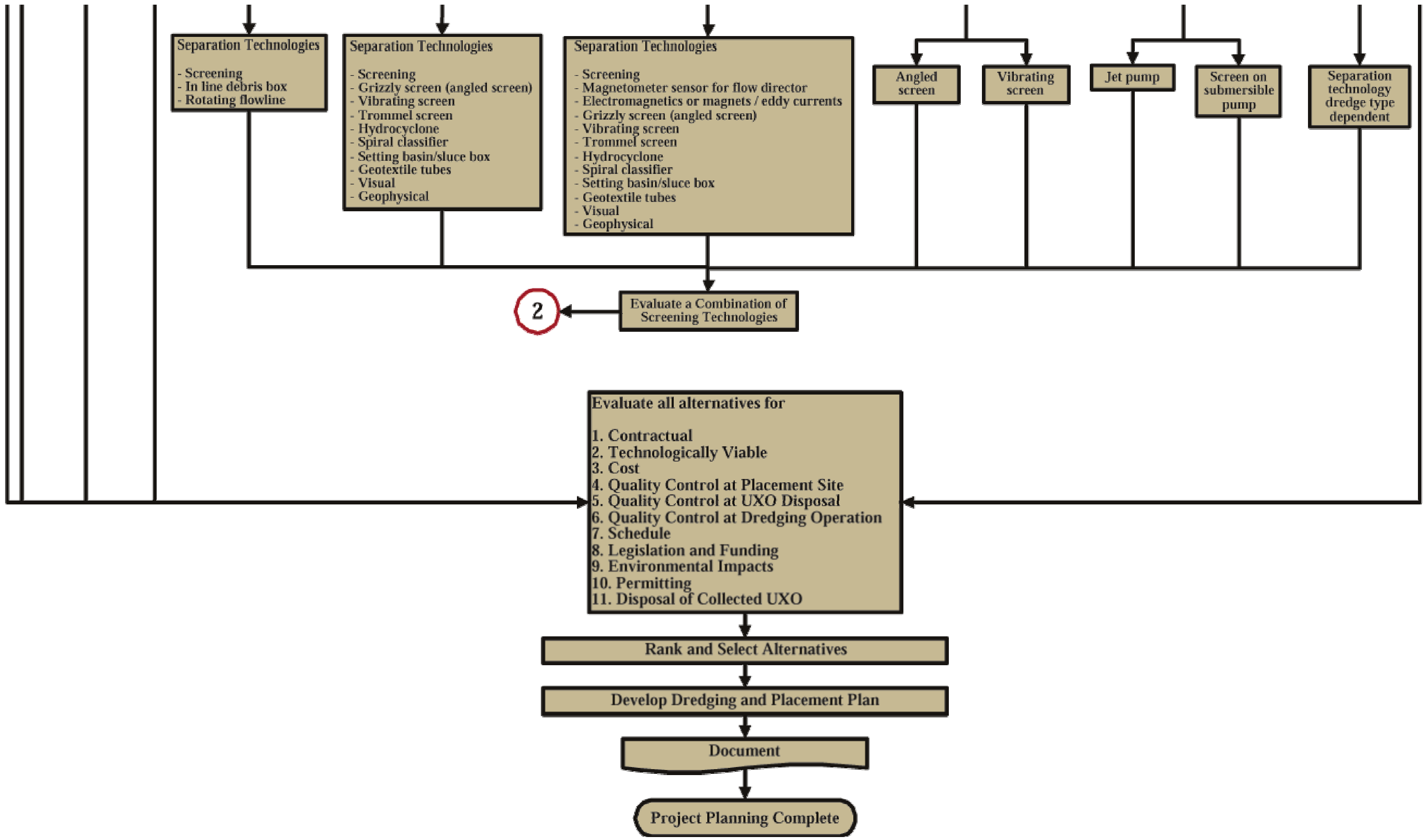
Other comments ------

APPENDIX B: DECISION FLOWCHART

UXO/Dredging Project Planning Flow Chart




Technically and economically viable to clear UXO from site prior to dredging?
Yes
No
Locate and remove UXO from dredge site
Detection devices
Removal method, divers mechanical
Conventional dredging
Document
Exclude UXO from Dredge
Select UXO separation Method selection
Collect and Separate UXO
1
Select dredge (Not applicable to mechanical dredge)
Size grate at dredge head. Calculate efficiency lose
Review issues related to leaving UXO on sediment bed
Is clean up of UXO required post dredging?
No
Dredge and leave UXO on seabed
Document
Yes
Dredge and use methods to remove excluded UXO from seabed
Dispose of UXO
Document
Rejection Threshold Identify smallest diameter of UXO to be excluded
Evaluate UXO and sediment separation techniques
Spot Remove Large UXO?
Yes
No
Detection device
Removal method divers/mechanical
Apply engineering and operational controls for blast/fragmentation/ chemical effects damage mitigation
Hydraulic dredge
Mechanical dredge
Other dredge types
Hopper dredge
Cutter head
Evaluate hazard points
a. Drag head/drag pipe vs. distance to hull and crew
b. Pump/distribution piping/ hopper vs. distance to crew and hull
c. Disposal from hopper
d. Pump out
e. Pump/pipeline vs. distance to crew and hull
f. Discharge line (floating submerged and shoreline)
Evaluate hazard points
a. Cutter head ladder pipe vs. distance to crew and vessel hull
b. Pump/hull discharge piping vs. distance to crew and vessel hull
c. Discharge pipeline (floating/ submerged/and shoreline) vs. distance to crew
d. Placement area crew and equipment
Evaluate hazard points
a. Clam shell/bucket excavation point vs. distance to hull and crew
b. Side cast into scow or barge vs. distance to crews and hull
c. Transport and dump distance to crew and hull
Evaluate hazard points on dredging methodology
Design and implement mitigation measures
a. Operational procedures
b. Blast/fragmentation/chemical suppression
c. Exclusion devices
d. Stand off safety distance
e. Site specific health and safety plan
Document
Dredge and separation method selection criteria:
a. Physical characteristics of material to be dredged
b. Quantities and physical layout of material to be dredged
c. Dredging depth
d. Location of both dredging and placement sites and distance between sites
e. Physical environment of and between the dredge and disposal placement areas
f. Method of placement
g. Production requirements
h. Type of dredges available
i. UXO characteristics
Dredging and UXO Separation Alternatives
Hydraulic dredge
Mechanical dredge
Other dredge types
Separate at suction
Separate at rehandling area
Separate at discharge
Onboard scow
Barge pump out
Separation location dredge type dependent


Separation Technologies
- Screening
- In line debris box
- Rotating flowline
Separation Technologies
- Screening
- Grizzly screen (angled screen)
- Vibrating screen
- Trommel screen
- Hydrocyclone
- Spiral classifier
- Setting basin/sluce box
- Geotextile tubes
- Visual
- Geophysical
Separation Technologies
- Screening
- Magnetometer sensor for flow director
- Electromagnetics or magnets / eddy currents
- Grizzly screen (angled screen)
- Vibrating screen
- Trommel screen
- Hydrocyclone
- Spiral classifier
- Setting basin/sluce box
- Geotextile tubes
- Visual
- Geophysical
Angled screen
Vibrating screen
Jet pump
Screen on submersible pump
Separation technology dredge type dependent
2
Evaluate a Combination of Screening Technologies
Evaluate all alternatives for
1. Contractual
2. Technologically Viable
3. Cost
4. Quality Control at Placement Site
5. Quality Control at UXO Disposal
6. Quality Control at Dredging Operation
7. Schedule
8. Legislation and Funding
9. Environmental Impacts
10. Permitting
11. Disposal of Collected UXO
Rank and Select Alternatives
Develop Dredging and Placement Plan
Document
Project Planning Complete